Mars Relay Operations

The Technical Challenges of Operating a Network at Mars

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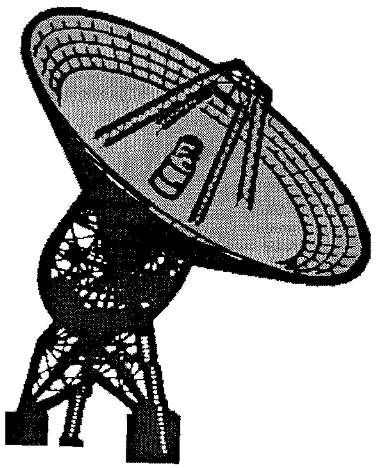
NASA/JPL

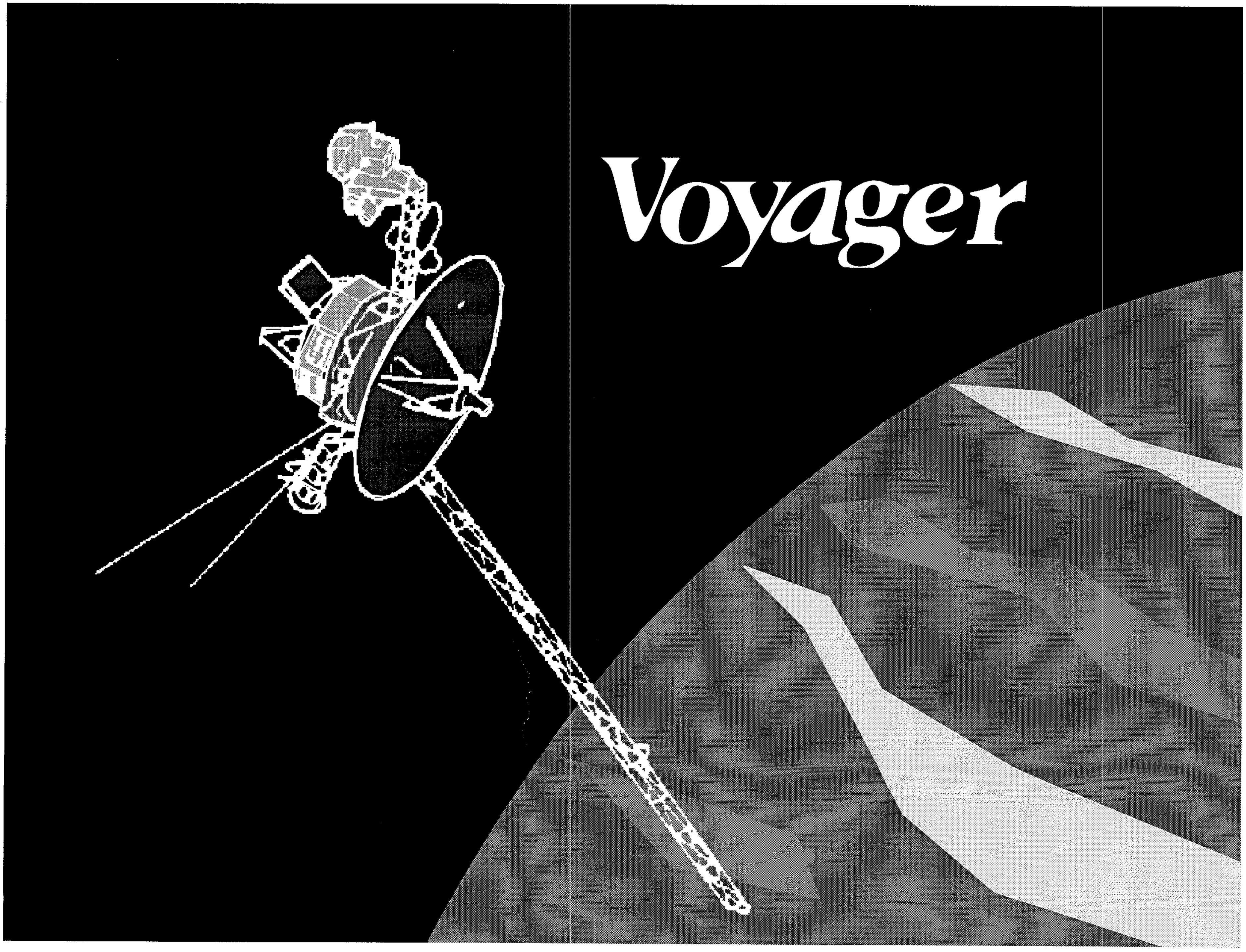
19 April 2002



What is the Deep Space Network?

How did it get this way?

Where are we going?

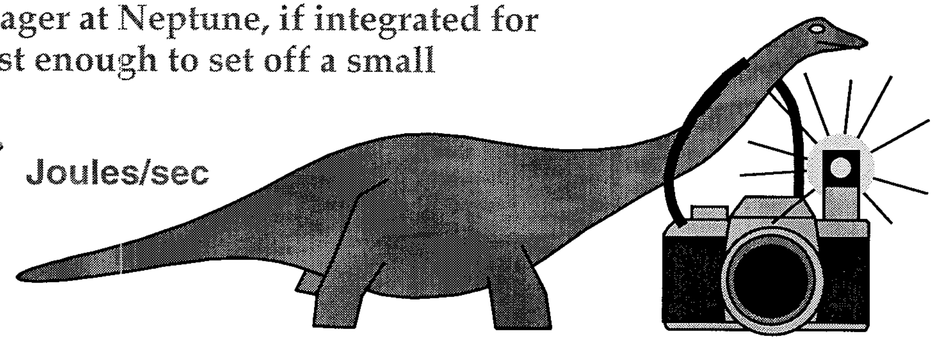

Voyager

CHARACTERISTICS OF DEEP SPACE MISSIONS

Received Signal Sensitivity:

The received energy from Voyager at Neptune, if integrated for 300 million years, would be just enough to set off a small photographic flashbulb!

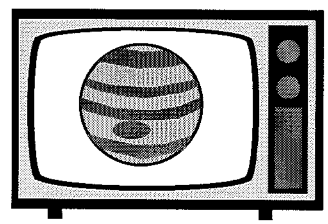
Received power = 10^{-16} Joules/sec



Command Power:

The DSN puts out enough power in commanding Voyager that it could easily provide high quality commercial TV at Jupiter!

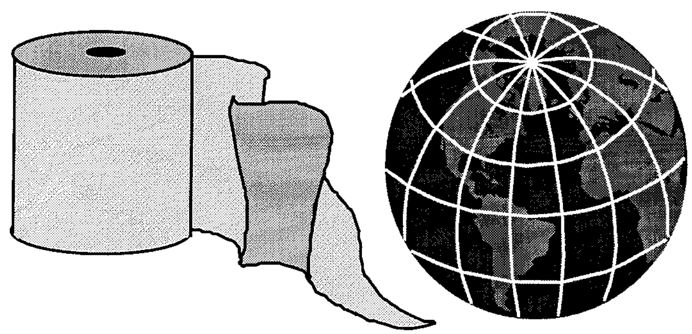
Transmitted power = 400 KW



Dynamic Range of the DSN:

The ratio of the received signal power to the DSN transmitting power is like comparing the thickness of a sheet of toilet paper to the entire Earth!

Ratio = 10^{21}

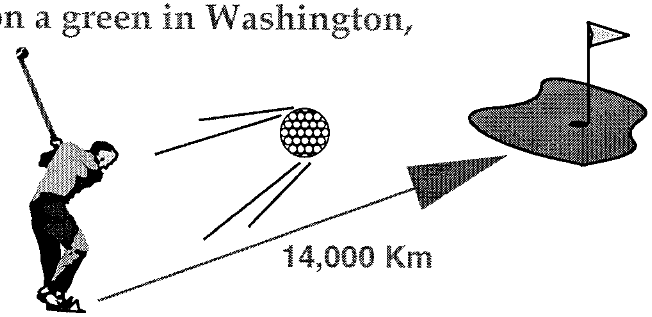


CHARACTERISTICS OF DEEP SPACE MISSIONS

Navigational Accuracy:

Voyager navigation at Neptune is equivalent to being able to tee – off from California and place the ball on a green in Washington, D.C.!

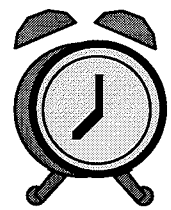
Angular accuracy = 50 nrad



Frequency Stability:

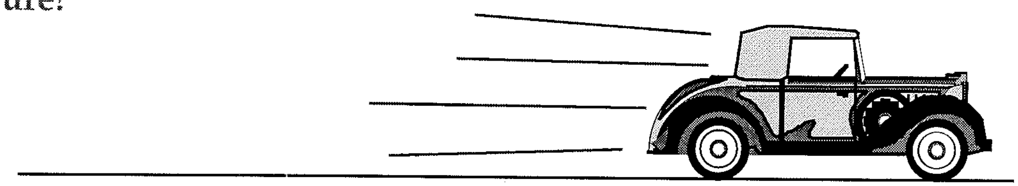
The DSN's atomic clocks used to achieve this navigation accuracy are so stable that only one second of error would accumulate every 3 million years!

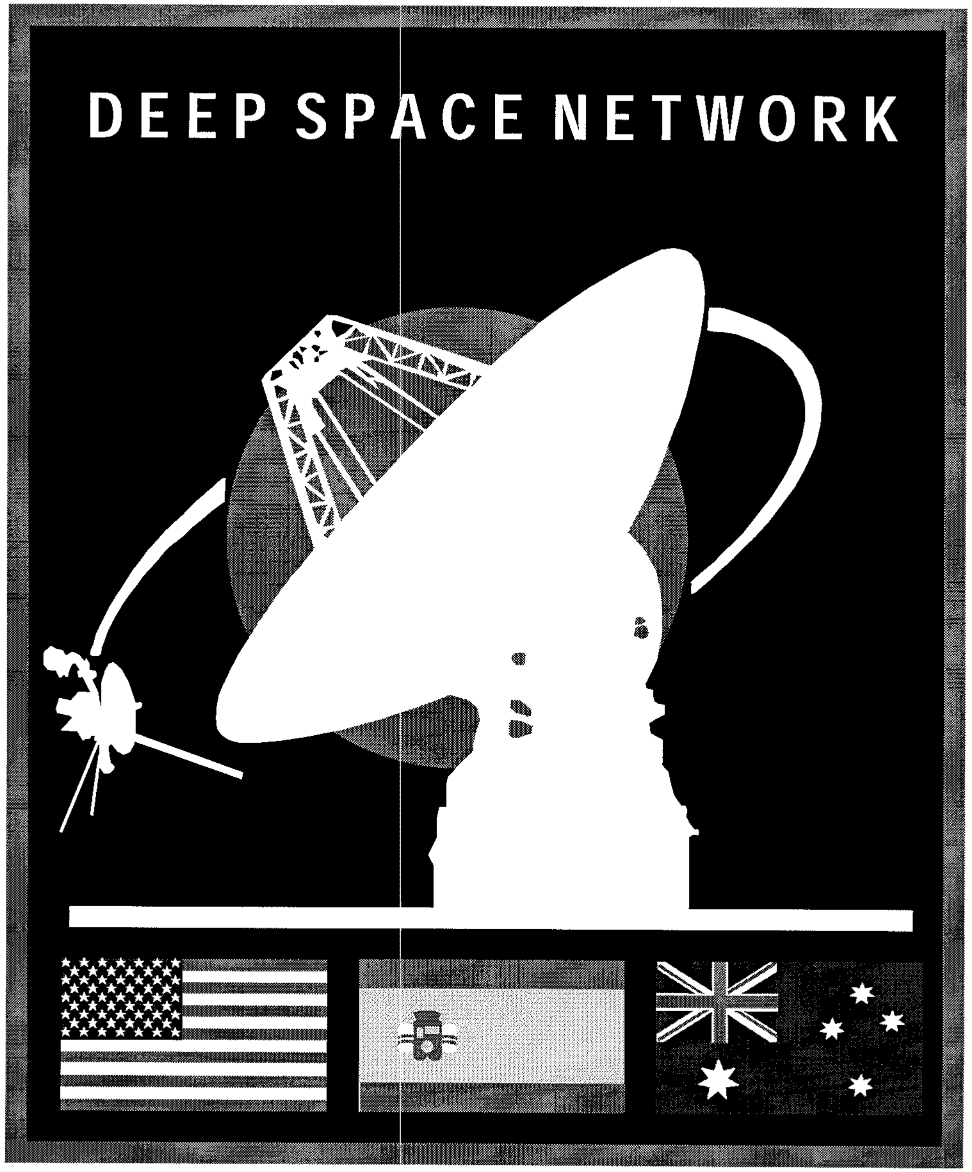
Allan variance = 10^{-12} in 1000 seconds



Once-in-a-lifetime Science Opportunities:

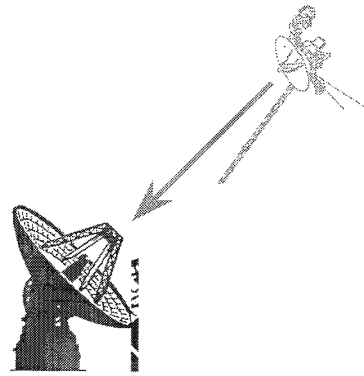
The data from a Voyager planetary encounter is more valuable than the most rare Earth elements! The reliability of the spacecraft and the DSN together is equivalent to driving an automobile for 3 billion miles without a single failure!

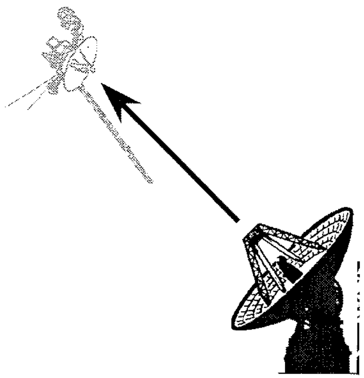



DEEP SPACE NETWORK

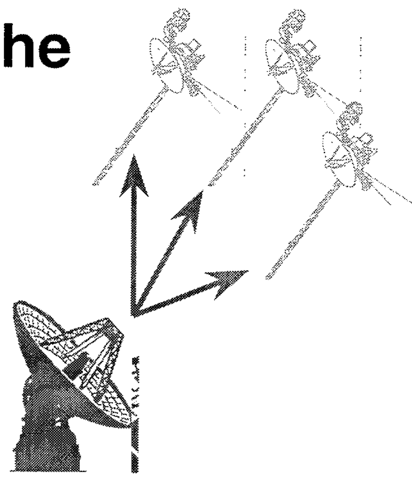
THE THREE MAJOR FUNCTIONS OF THE DSN:

TELEMETRY
Receiving data from the spacecraft





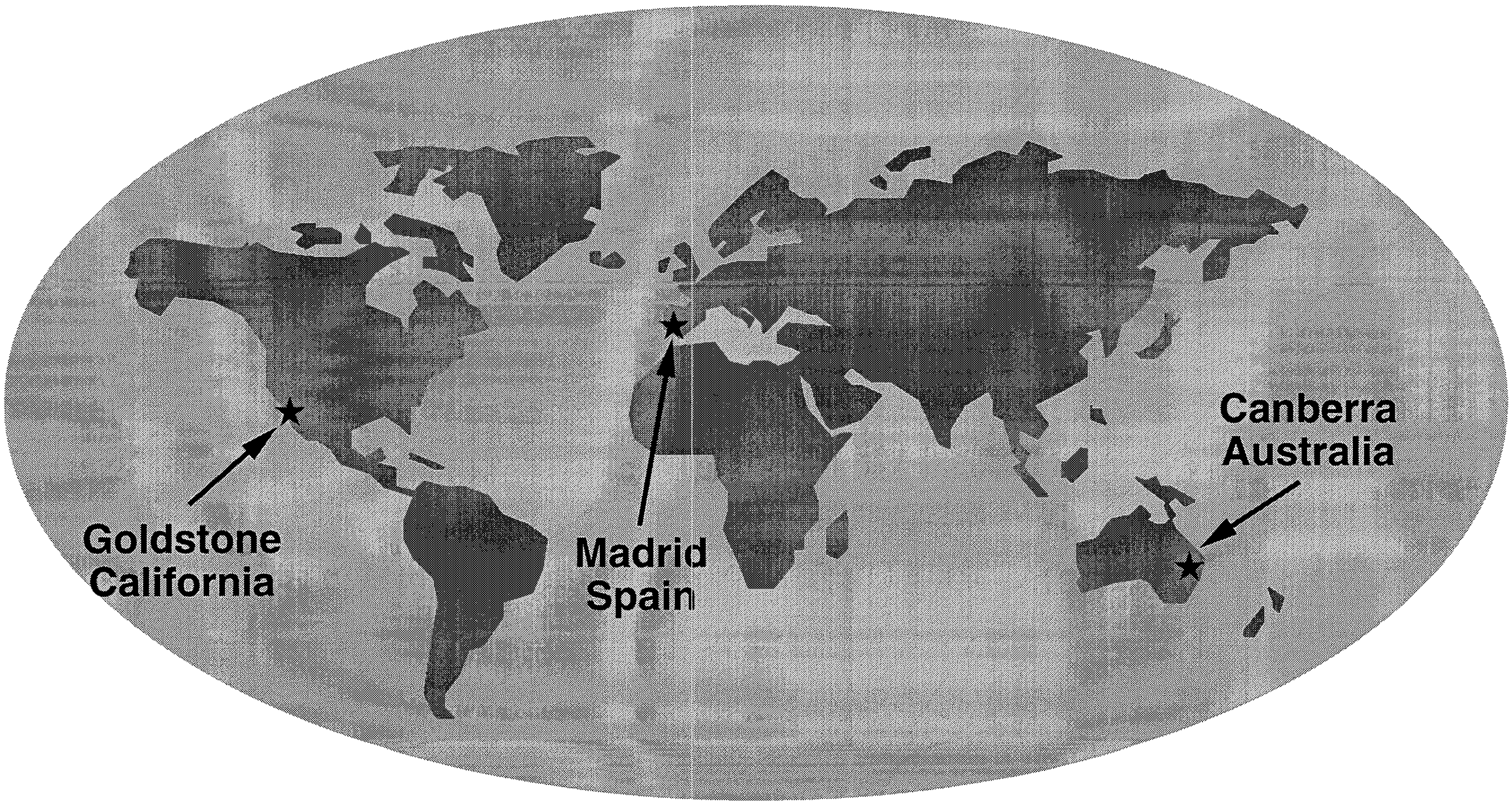
COMMAND
Sending data to the spacecraft



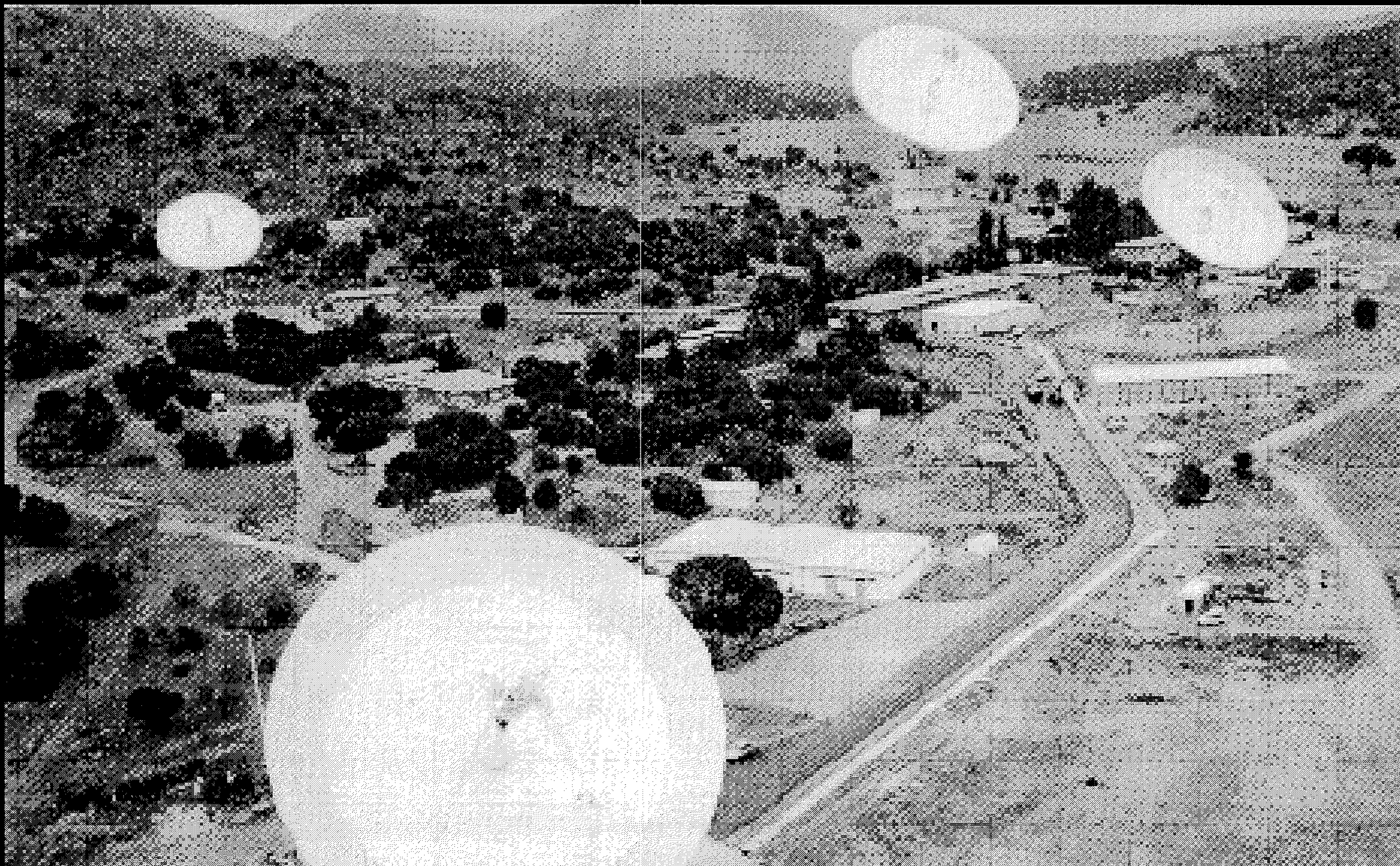
NAVIGATION
Determining the spacecraft's position and velocity

DSN FACILITIES

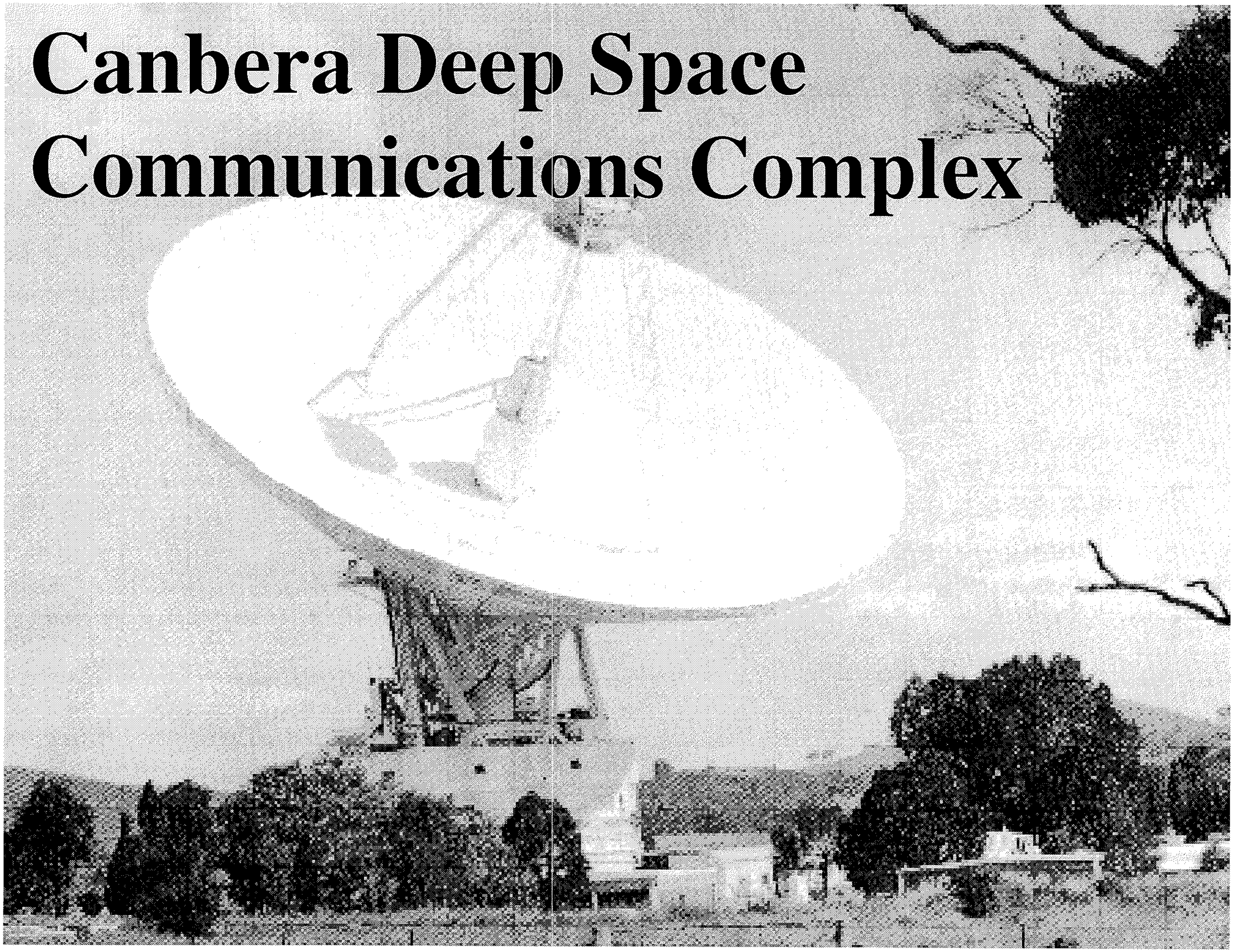
The DSN operates three deep-space communications complexes
that near continuous coverage of deep space missions is achiev



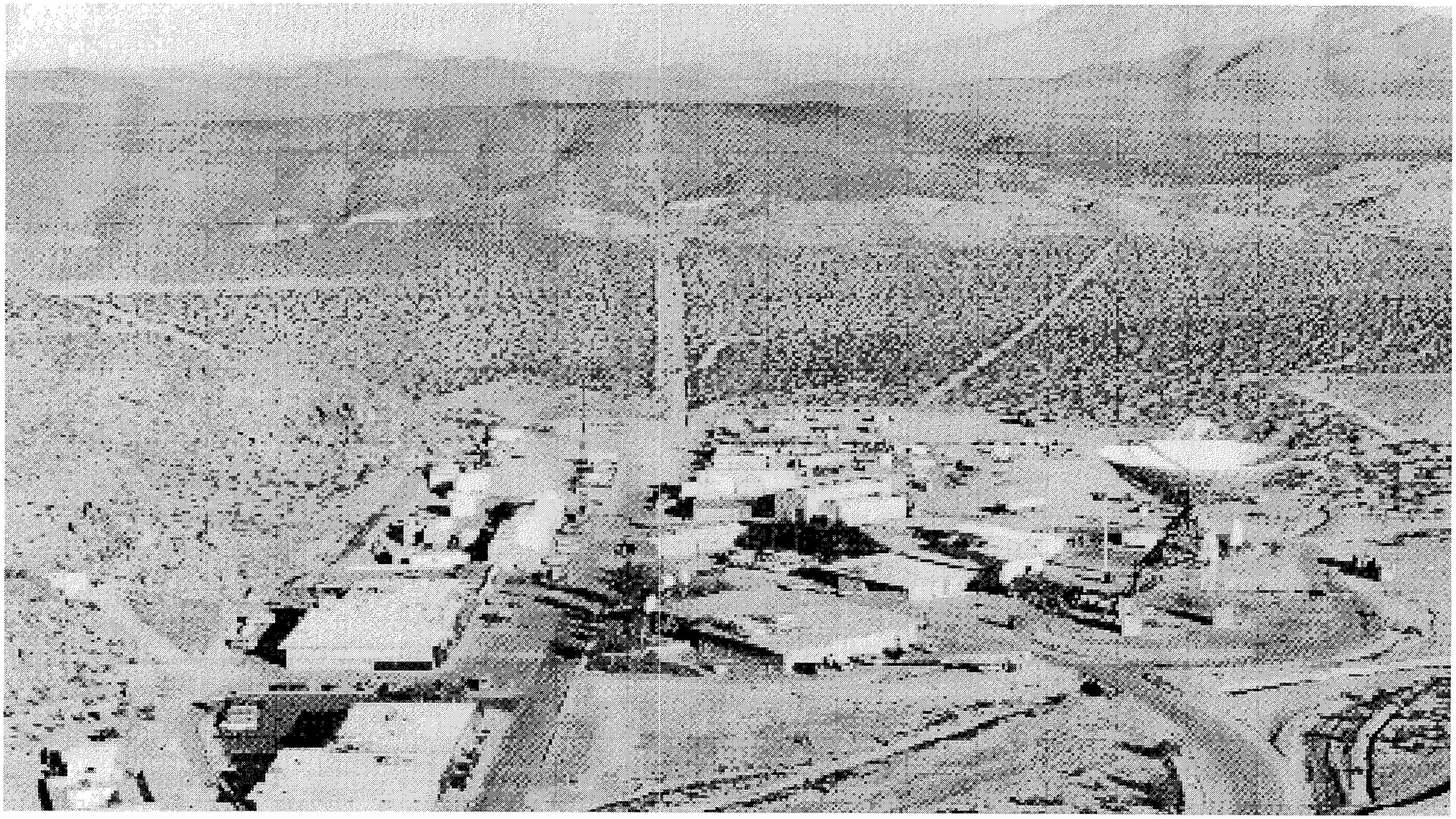
The DSN also operates facilities at JPL
and at Cape Canaveral



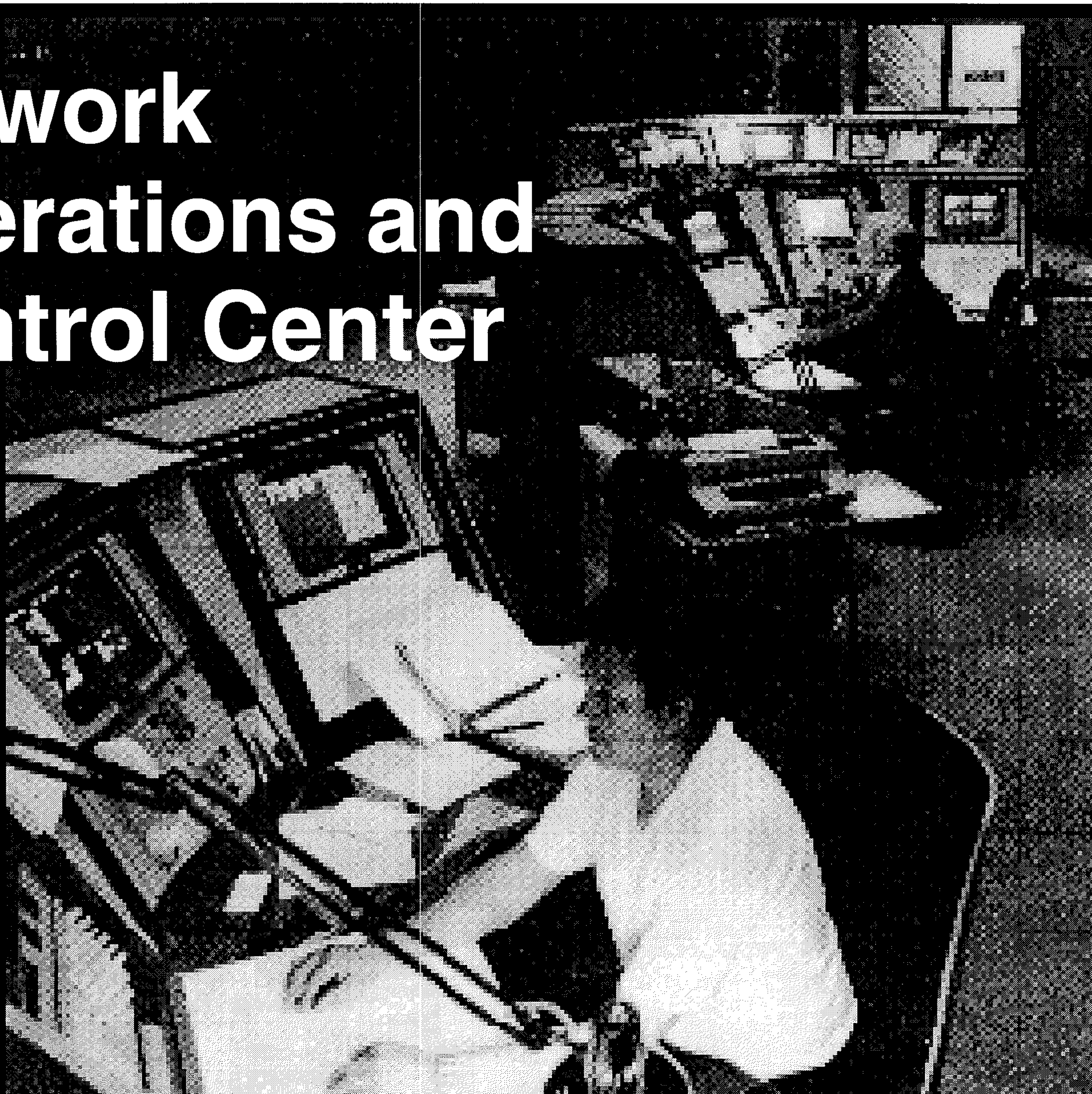
Madrid Deep Space Communications Complex


Canbera Deep Space
Communications Complex

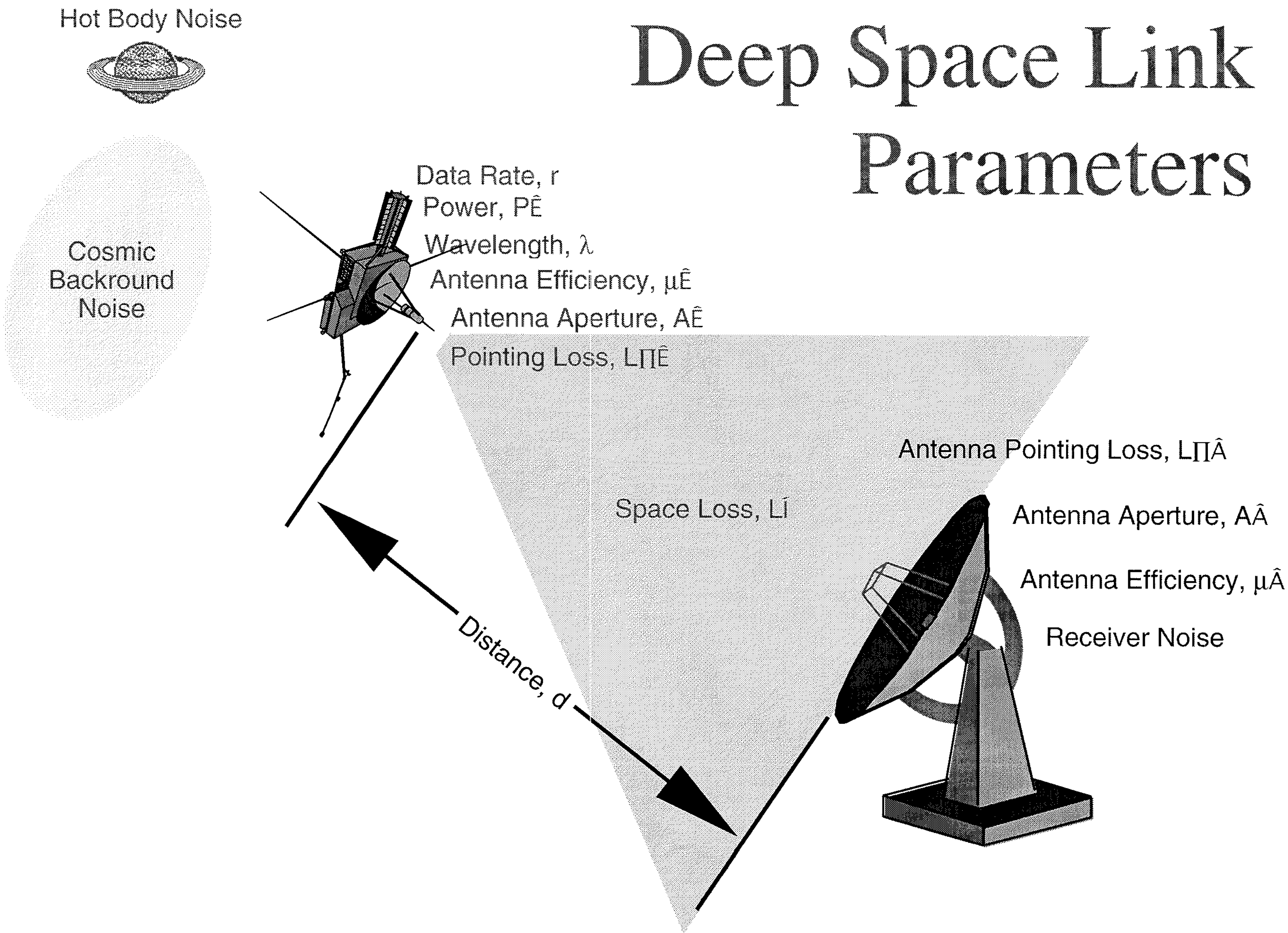
Goldstone Deep Space Communications Complex



Network Operations and Control Center



Deep Space Link Parameters



Deep Space Link Equations

Space Loss

$$L\acute{I} = \left(\frac{\lambda}{4\pi d}\right)^2$$

Antenna Gain

$$G\wedge = \frac{4\pi\mu A}{\lambda^2}$$

Received Power Per Bit

$$P\hat{A} = P\hat{E}G\hat{E}L\Pi\hat{E}L\acute{I}L\Pi\hat{A}G\hat{A}/r$$

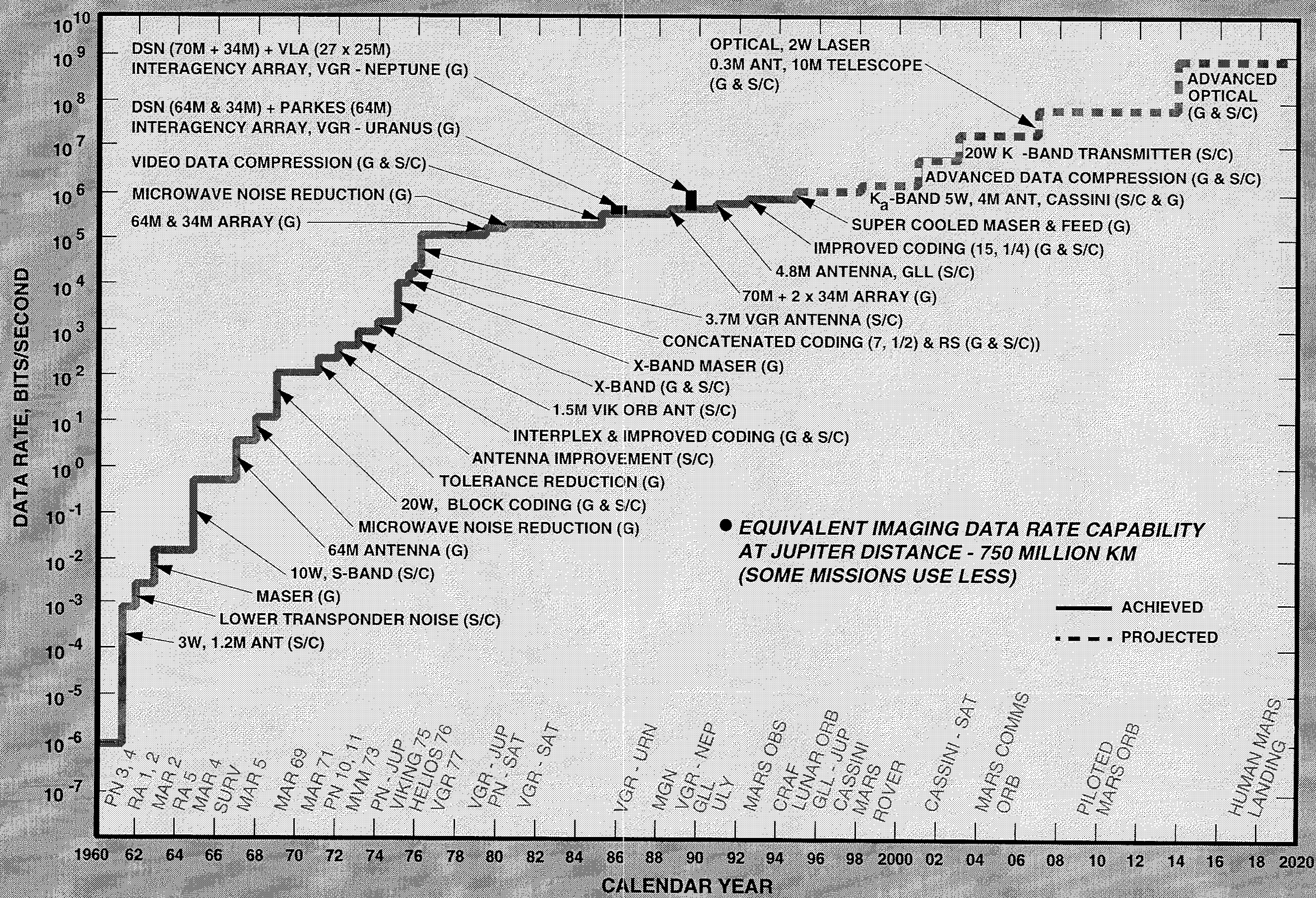
Noise Spectral Density

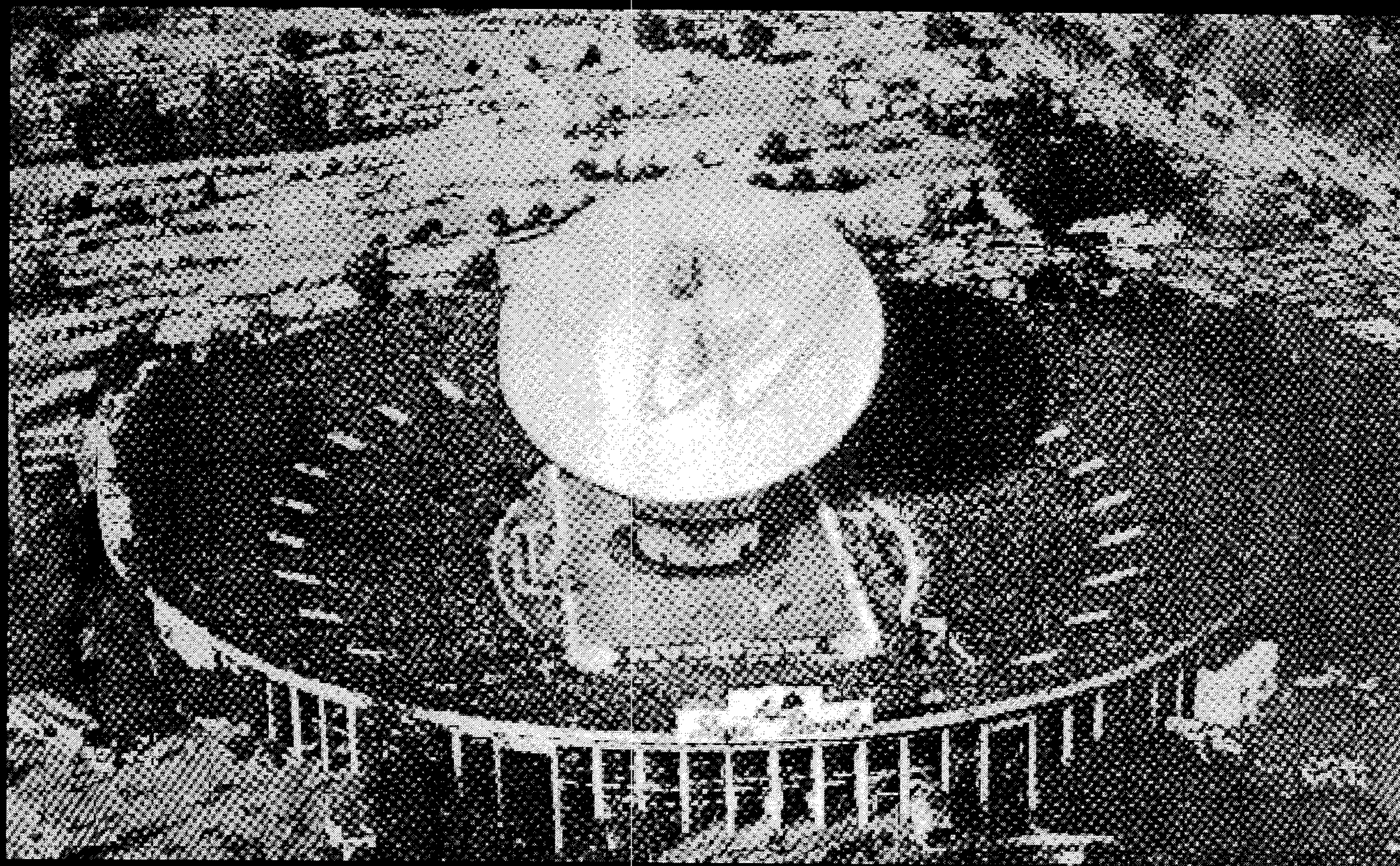
$$N^{\circ} = kT$$

Noise Sources

$$\begin{aligned} T = {} & T_{\text{cosmic background}} \\ & + T_{\text{hot bodies}} \\ & + T_{\text{RFI}} \\ & + T_{\text{atmosphere}} \\ & + T_{\text{receiver}} \end{aligned}$$

HISTORY OF TELEMETRY PERFORMANCE





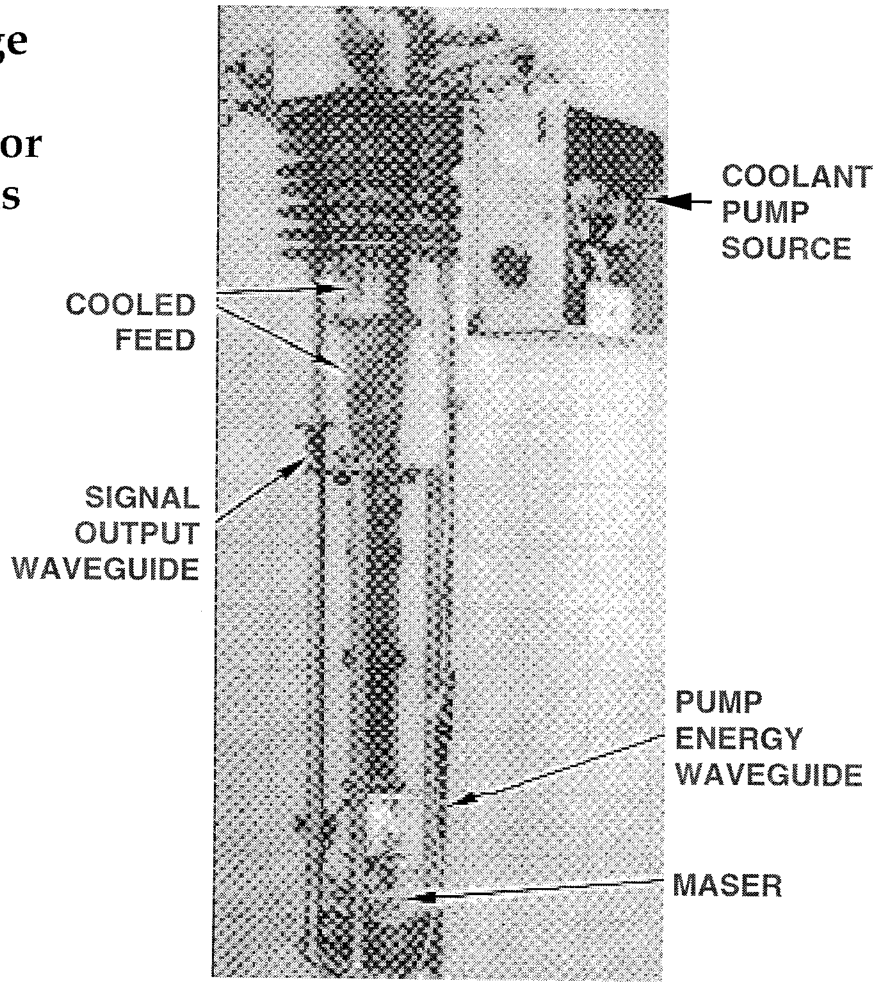
70 METER ANTENNA IN THE ROSEBOWL

LOW NOISE AMPLIFIERS AND FEEDS

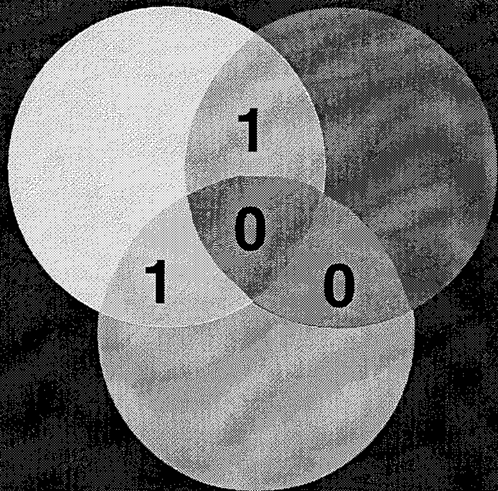
Many radio observatories have large antennas - only the DSN uses the lowest noise feeds and amplifiers for collecting the signals from the focus of the dish

The DSN routinely uses maser amplifiers cooled to 4 degrees Kelvin

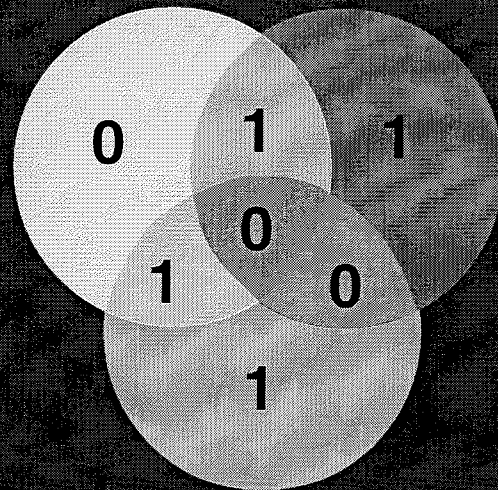
The latest technology in the DSN makes use of cooled feeds as well - and uses masers cooled to 1.9 k!



An example of coding: the (7, 4) Hamming code

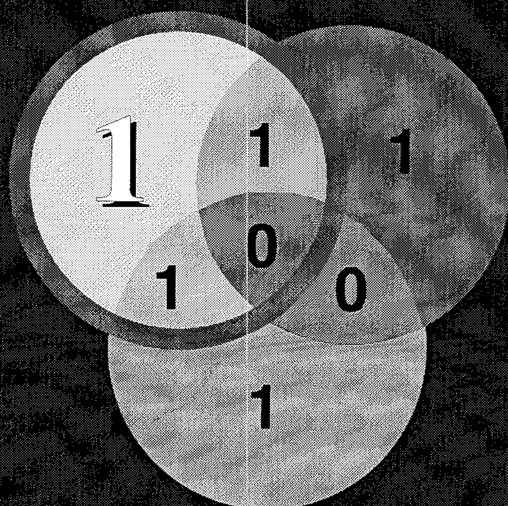


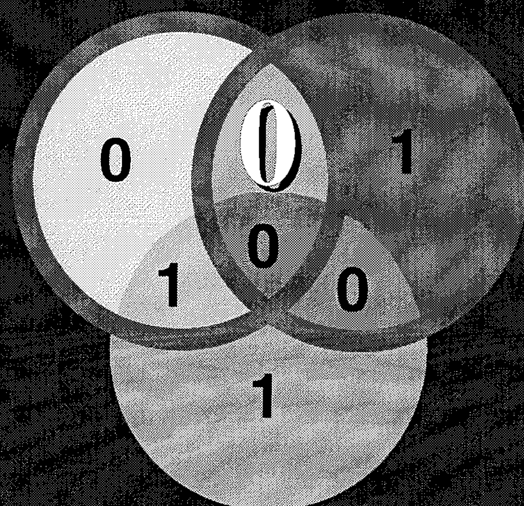
Place 4 information bits in the intersections of the Venn diagram



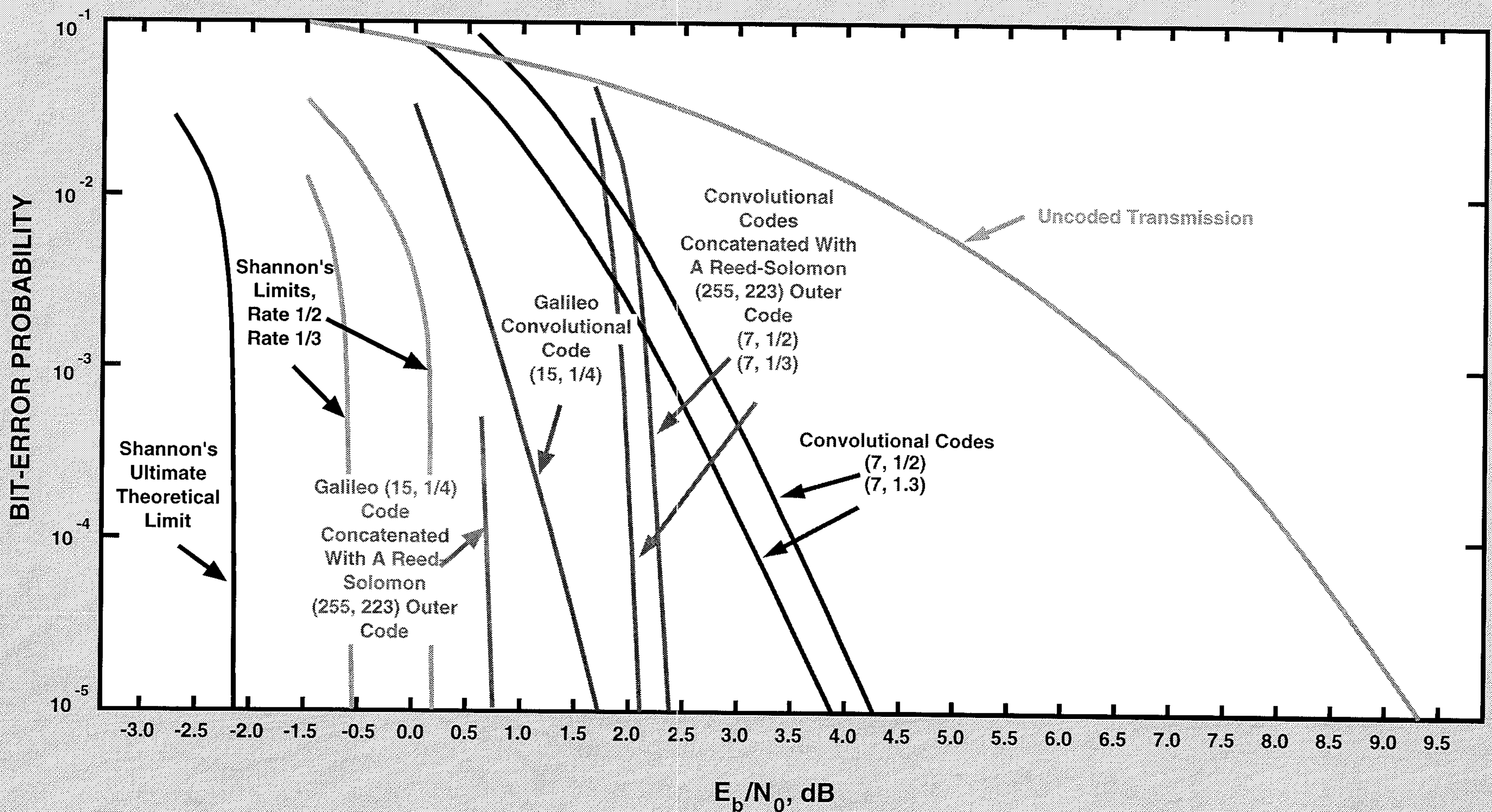
Fill in the rest of the diagram so that the large circles have an even number of 1's

If a single error occurs, it can be corrected by locating the circles with an odd number of 1's and changing the bit in their intersection

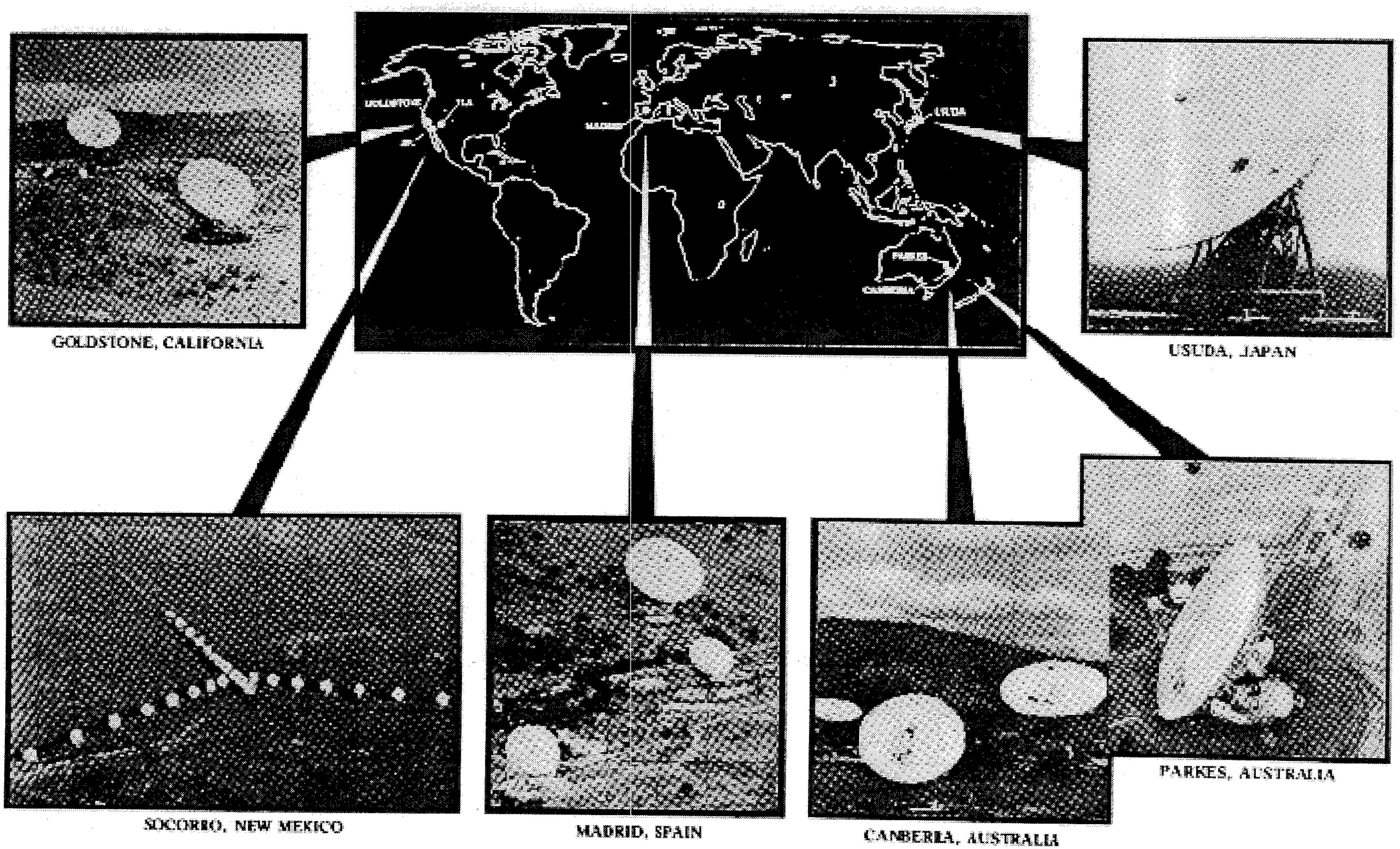




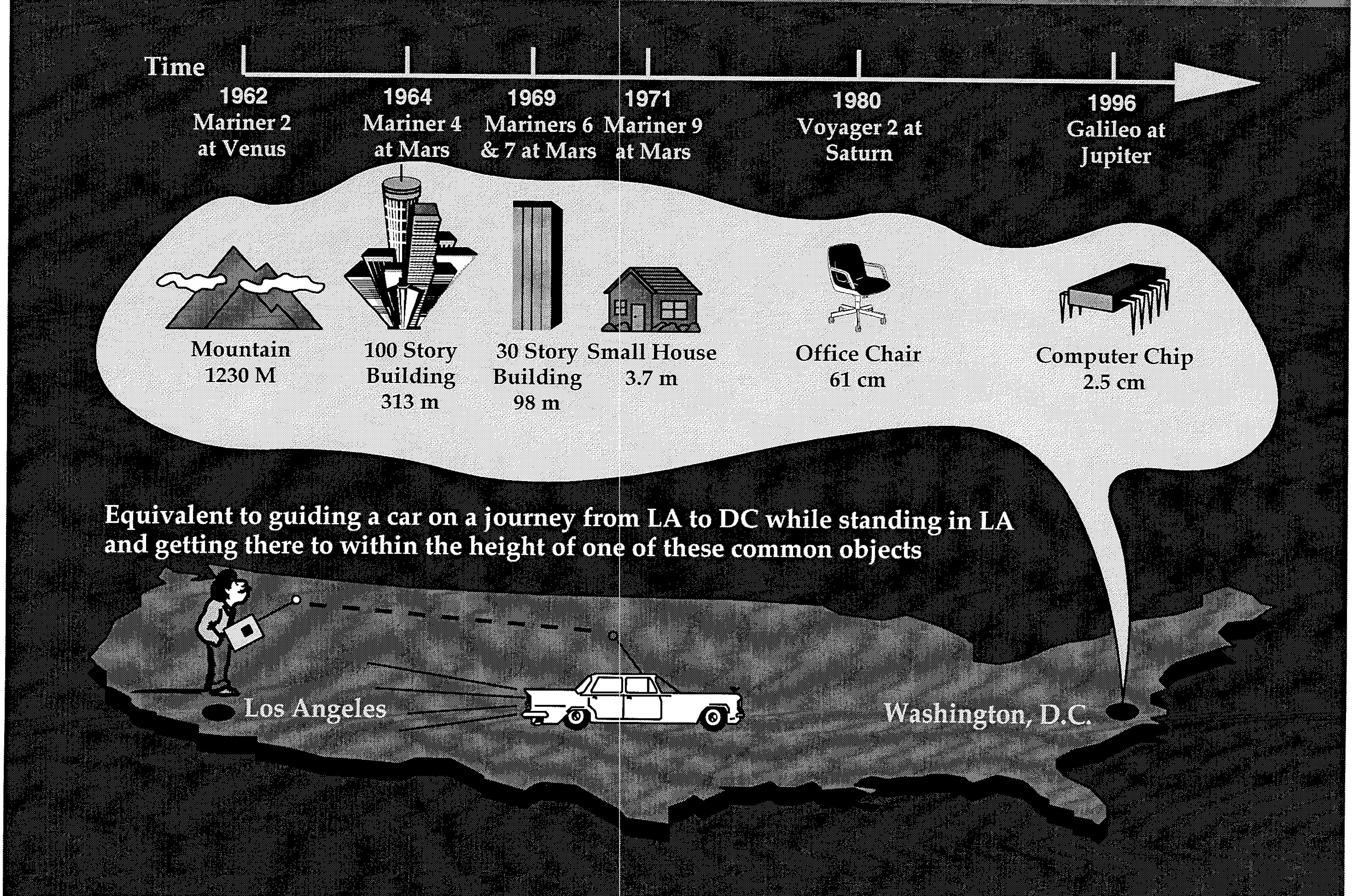
Comparison of Several Coding Schemes



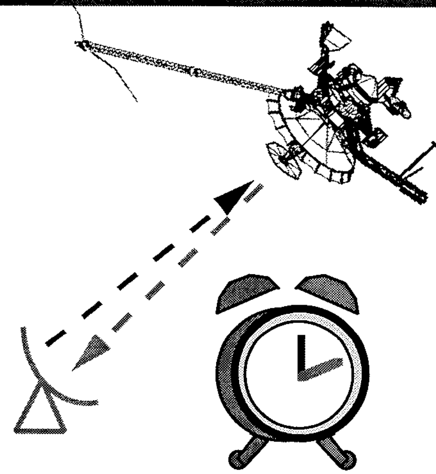
Voyager International Tracking Network



History of Navigational Capability



The Two Main Navigation Data Types Used by the DSN

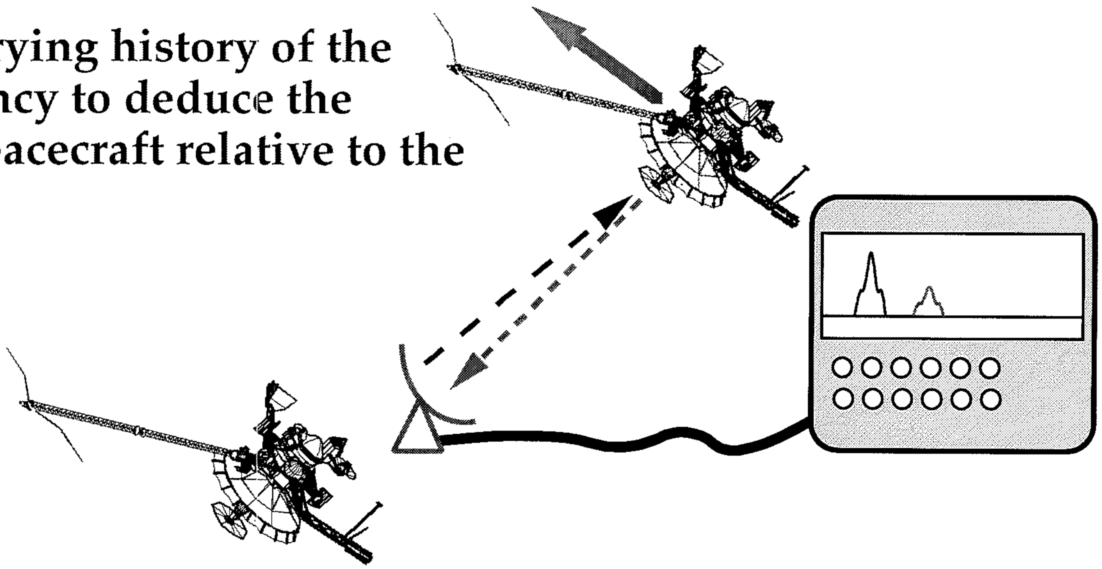


RANGING:

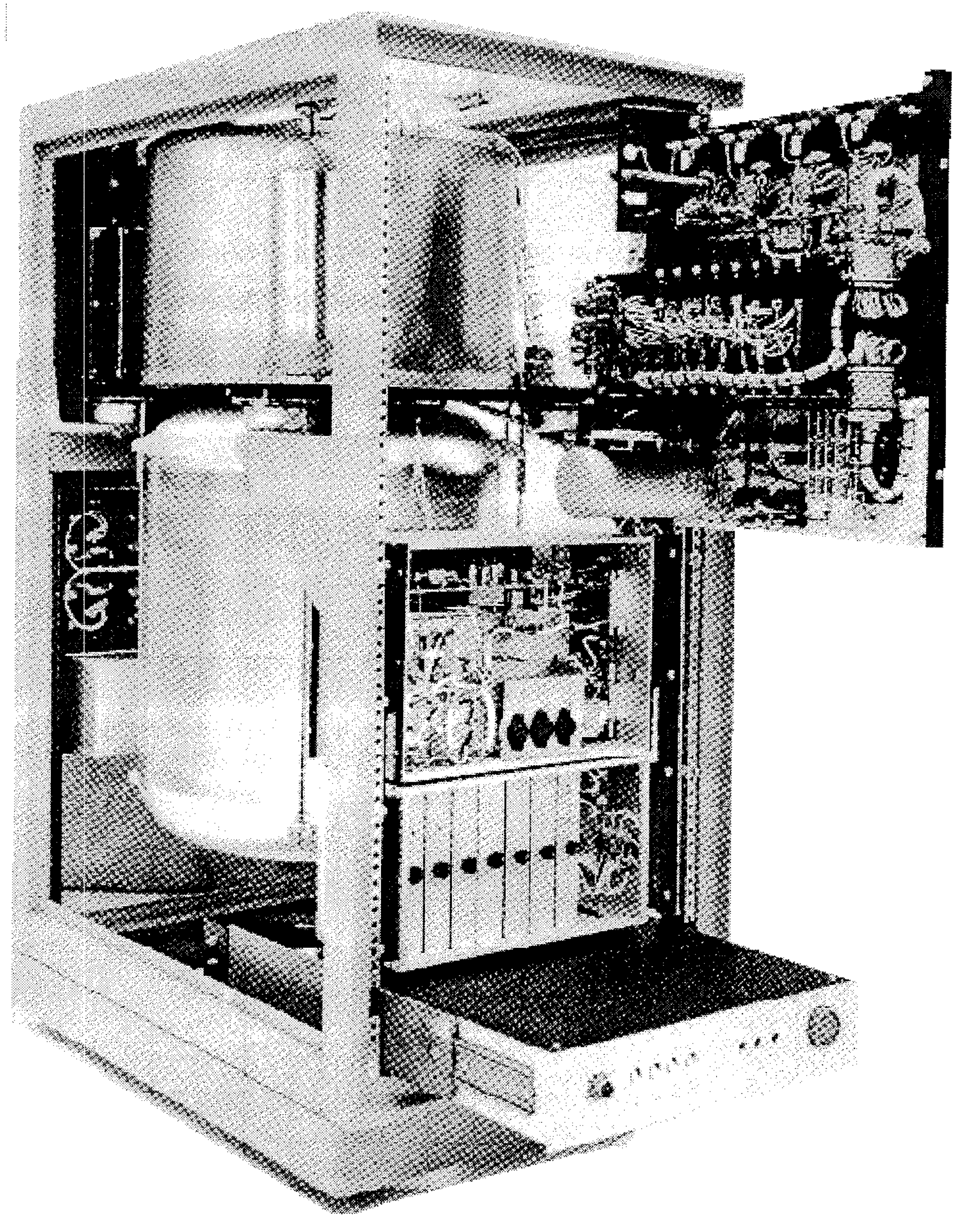
Use the length of time for the signal to propagate from the DSN to the spacecraft and back to deduce the distance to the spacecraft

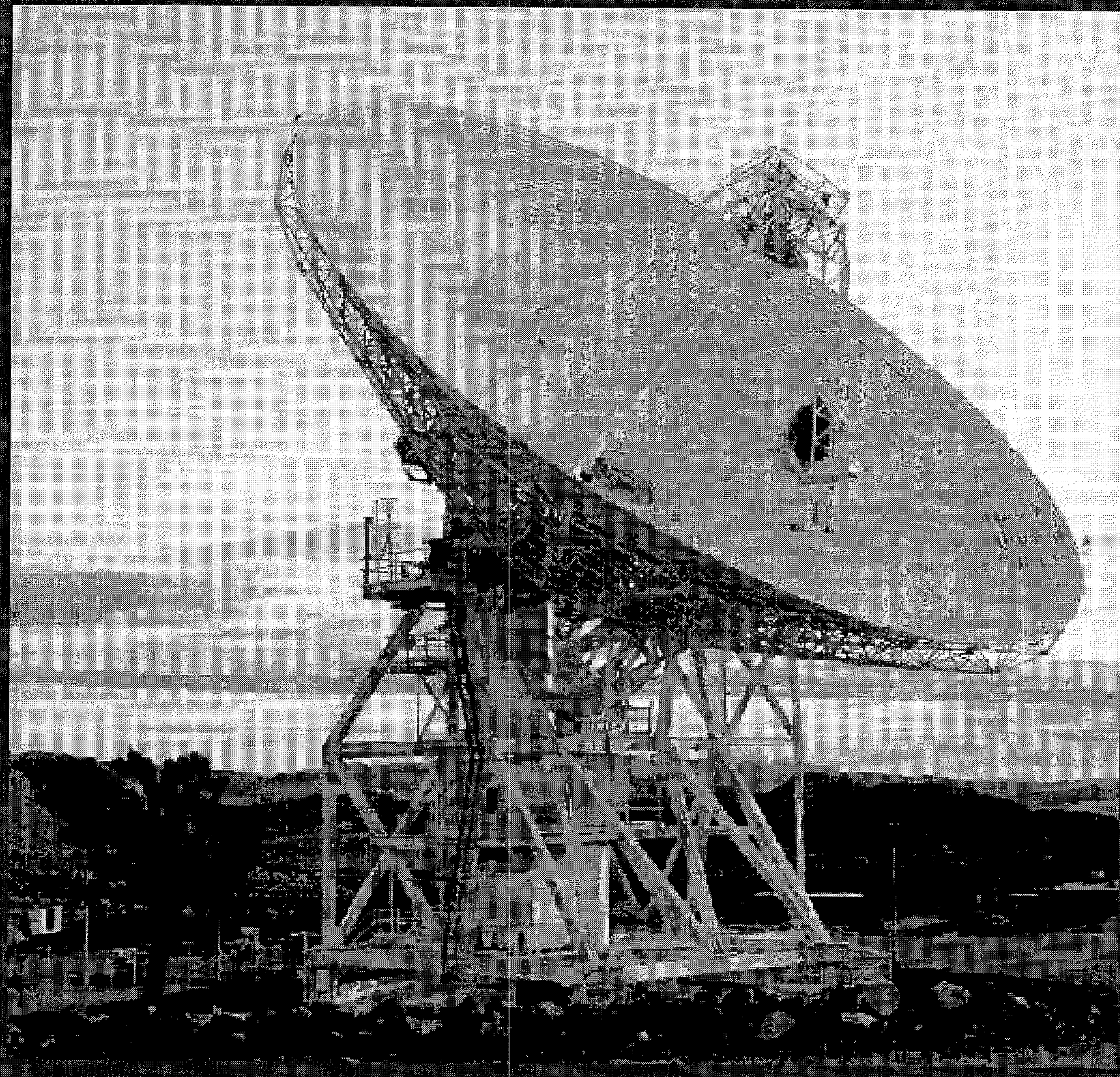
DOPPLER:

Use the time-varying history of the received frequency to deduce the motion of the spacecraft relative to the DSN

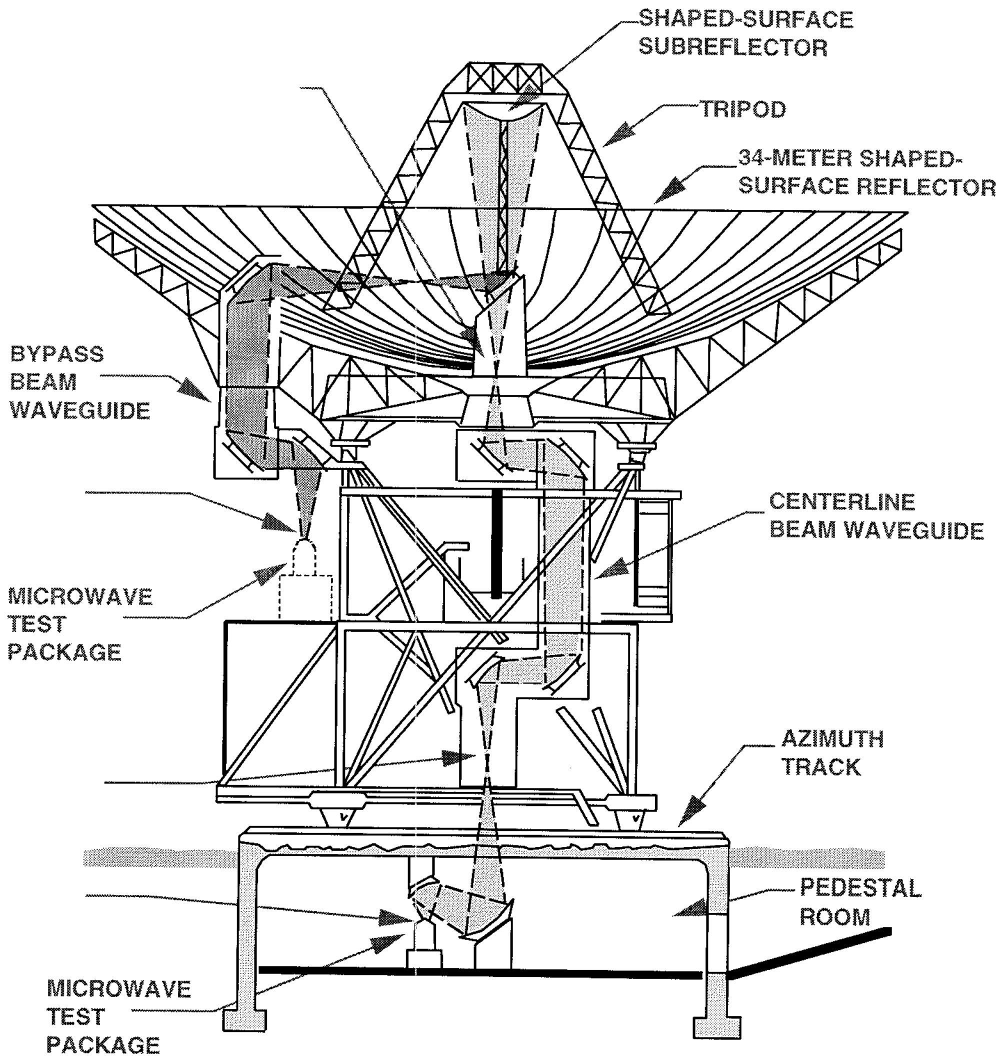


Hydrogen Maser Frequency Standard





Deep Space Station (DSS) 13



Ability to Communicate in Deep Space

- 1) Received Signal Power P_r
- 2) Signal to Noise Ratio (P_r/N_o)
- 3) How Efficiently SNR is utilized

Received Signal Power

- $P_r = \rho \mu A_r$

Received Power = Power Flux Density * Effective Aperture of Receive Antenna

- $\rho = EIRP/4\pi r^2$

Power Flux Density = $(P_T G_T)/4\pi r^2$

Received Signal Power

Voyager at Neptune - Parameters

- Voyager Spacecraft
  - P_T = 21,3 W (Transmit Power)
  - G_T = 65.000 unitless (Gain)
- DSN 70M Antenna
  - $A_r = 3.848\ m^2$
  - μ = 65%
- Spacecraft Distance to Earth at Neptune
  - 29 AU $\cong 4{,}4 * 10^{12}$ m

Received Signal Power

Voyager at Neptune - calculation

- $\rho = EIRP/4\pi r^2$
- $\rho = (21{,}3W)\ (65.000)/[(4\pi)(4{,}4*10^{12}m)^2]$
- $\rho = 7{,}15 * 10^{-20}\ W/m^2$

- $P_r = \rho\mu A_r$
- $P_r = (7{,}15 * 10^{-20}\ W/m^2)\ (.65)\ (3.848m^2)$
- $P_r = 1{,}78 * 10^{-16}\ W$
- An Extremely Weak Signal!

Signal to Noise Ratio (Pr/No) - 1

- N_o = Noise Spectral Density
- $N_o = kT$
  - K = Boltzmann's constant (1.38×10^{-20} mW/K Hz)
  - T = System Noise Temperature
- DSN's T $\cong$ 28,5 K
- $N_o = (1.38 \times 10^{-20}\text{mW/K Hz})(28.5\text{K})$

  $= 3{,}9 \times 10^{-22}$ W/Hz

Signal to Noise Ratio (Pr/No) - 2

- $P_r = 1{,}78 * 10^{-16}$ W
- $N_o = 3{,}9 * 10^{-22}$ W/Hz
- Factor in Losses throughout the link
  - Circuit, pointing, modulation, etc
  - L = 0.7 unitless
- $P_r L / N_o = 319.487$ Hz

Signal to Noise Ratio (Pr/No) - 3

- $P_r/N_o = [EIRP] * [G_r/T_r] * [1/K] * [\lambda/4\pi\rho]^2$

↓

Total Received Power to Noise Spectral Density Ratio

↓

Effective Isotropic Radiated Power

↓

Receiving Antenna Gain/Noise Temperature

↓

1/Boltzmann's Constant

↓

Wavelength & Geometry

Signal to Noise Ratio (Pr/No) - 4

Example: Isotropic Backyard Receiver

- $P_r/N_o = \quad [EIRP] * [G_r/T_r] * [1/K] * [\lambda/4\pi\rho]^2$

- Challenge:
  - Receive a signal from Mars from Spacecraft Low Gain Antenna
  - Backyard receiver has ambient system noise temperature
  - Gain is unity for isotropic antenna

- $P_r/N_o = [10W] * [1/300K] * [10^{23} W/K\ Hz] * [2.2*10^{-28}]$

- $P_r/N_o = 7*10^{-7}$ Hz

Signal to Noise Ratio (Pr/No) - 5

Example: DSN cryogenically cooled Receiver/70M antenna

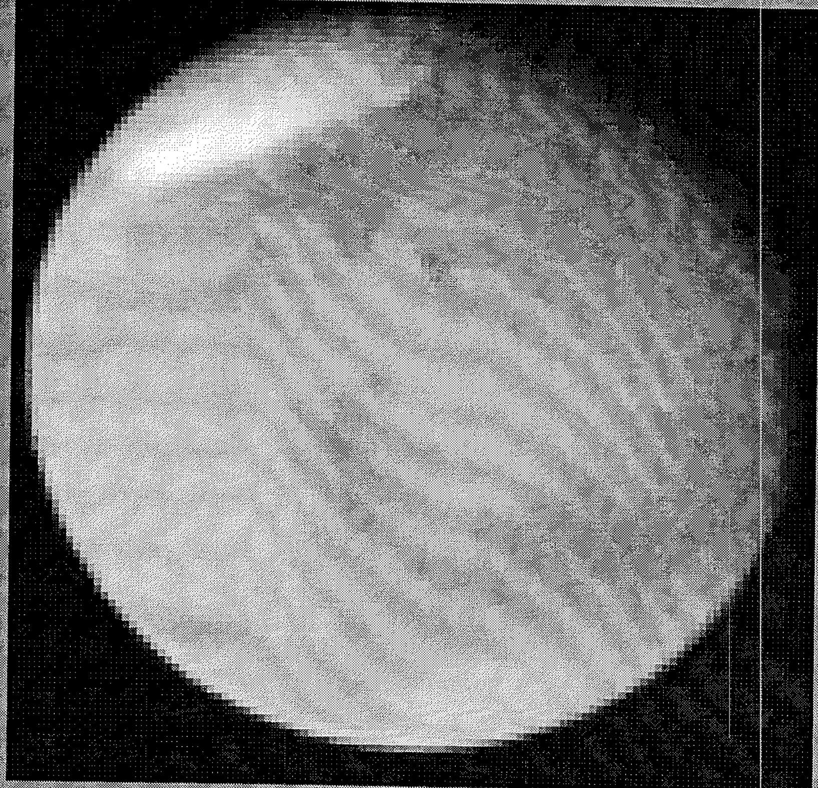
- $P_r/N_o = [EIRP] * [G_r/T_r] * [1/K] * [\lambda/4\pi\rho]^2$
- Challenge Met:
  - Receive a signal from Mars from Spacecraft Low Gain Antenna
  - DSN receiver has system noise temperature of $\cong$ 30 K
  - 70M Antenna Gain is $\cong$ 25 Million over Isotropic antenna
- $P_r/N_o = [10W] * [10^{7.4}/30K] * [10^{23} W/K\ Hz] * [2.2*10^{-28}]$
- $P_r/N_o = 184\ Hz$
- Comparison of Reception Capability $= 2,5 * 10^8$

How efficiently SNR is utilized

- How much telemetry can be returned is a function of:
  - Link SNR available
  - The BER/FER required on the link (E_b/N_o to FER curves)
    - » Dependent upon sensitivity of the data types to errors
    - » Typical telemetry link specified at $1* 10^{-6}$ BER or $1*10^{-4}$ FER
    - » The advent of Link Retransmission mechanisms will change operations
  - Efficiency of the link dependent upon:
    - » Coding & Modulation chosen
    - » Coding gain from Forward Error Correcting Codes
    - » Move towards Turbo Codes and Bandwidth Efficient Modulation
  - Amount of Link Margin the project holds in reserve

Next Missions to the Planets

Telecommunications Summary

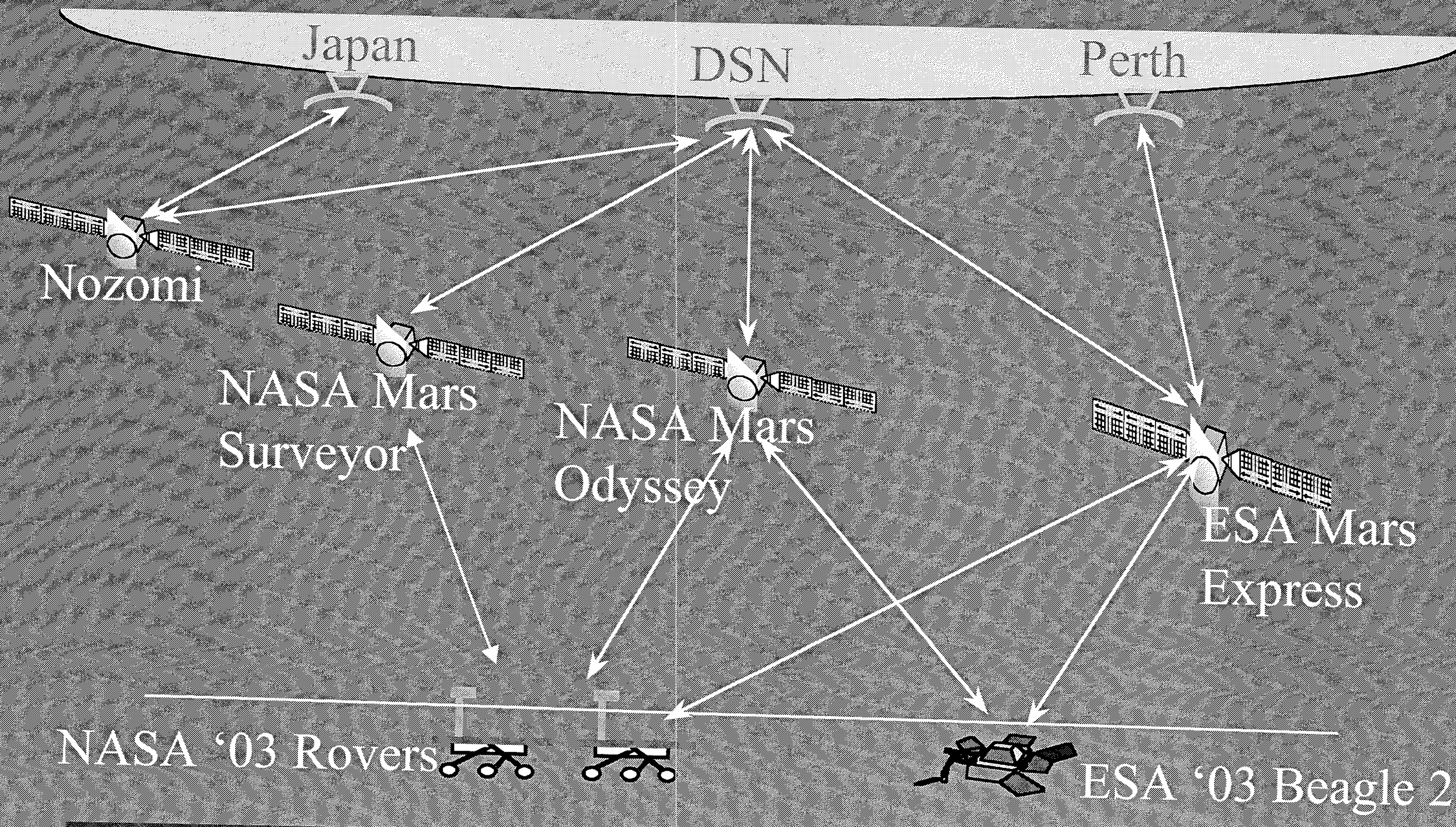


From
2001: Mars Odyssey
To
2014: Mars Sample Return

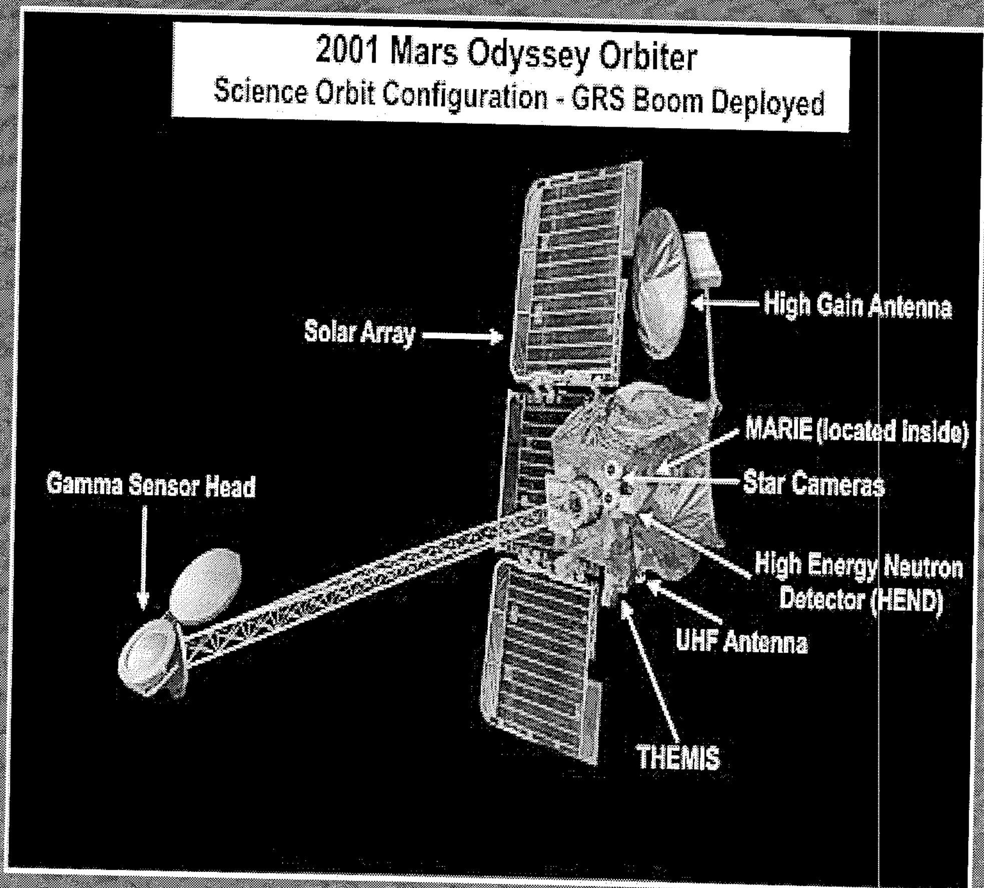
The Present and the Near Future

- The Voyager missions have been the turnaround point of the exploration of the solar system : from discovery using fly-byes to exploration
- The overall number of missions decreased from the '70s but is increasing the complexity and the capability of the spacecraft
- The data return from each mission is dramatically increasing. The deep space link moving from S (2GHz) to Ka (32 GHz) band.

Mars Scenario 2003-2006



Mars Odyssey



- **Primary mission: 1 Martian year (orbit insertion: 23-10-01)**
- **Extended Mission: 1 Martian year**
- **Orbit: 400Km polar, circular and sun-synchronous**

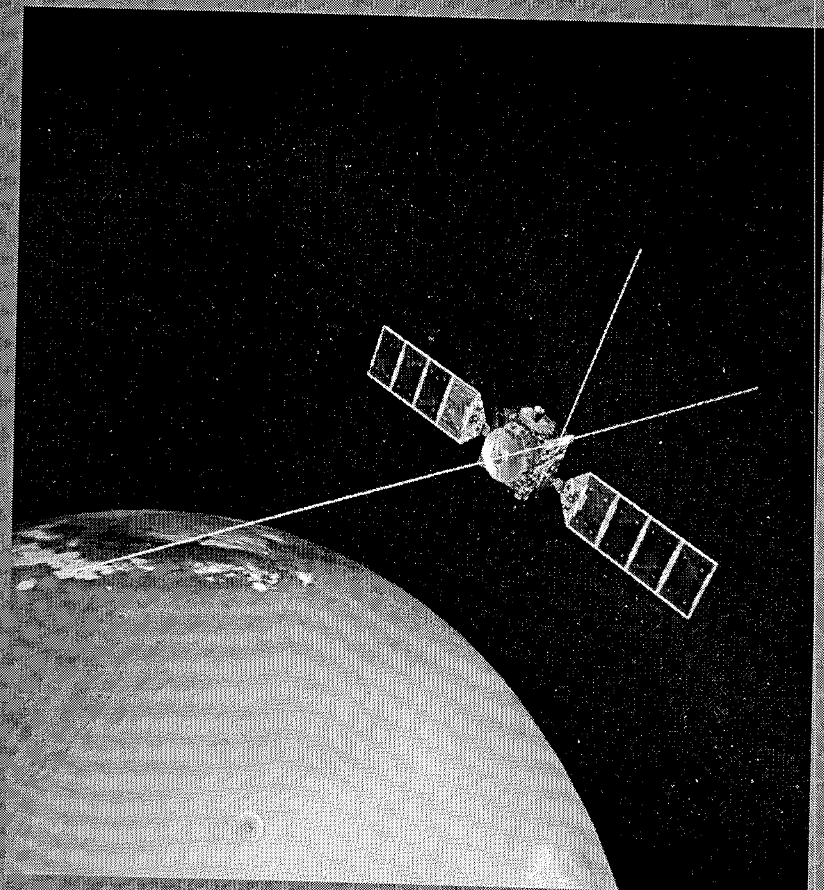
Mars Odyssey: Deep Space Link

- Deep Space Link Frequency: X band
- RF Power: 15W
- Data rate:
  - forward link: 125-2000bps
  - return link: 28-110kbps
- Near Continuos Availability on DSN 34m (BWG) or 70m antennas
- 1.6m High Gain Antenna

Mars Odyssey: Proximity Link

- Proximity Link Frequency: UHF
- RF Power: 10W
- Data Rates for forward and return link: 8, 32, 128, 256kbps
- Polarization: RHCP
- Modulation: PCM/Bi-Phase/PM with residual carrier
- Coding: uncoded or Convolutional (7,1/2)
- Antennas: Quadrifilar Helix

Mars Express



- Primary mission: Dec 03-Nov 05
- Extended Mission: Nov 05-Jun 08
- Orbit: elliptical near polar
  - Initial:
    apoapsis = 11559Km
    periapsis = 258.9Km
  - After 440 days:
    apoapsis = 10107Km
    periapsis = 298.4Km

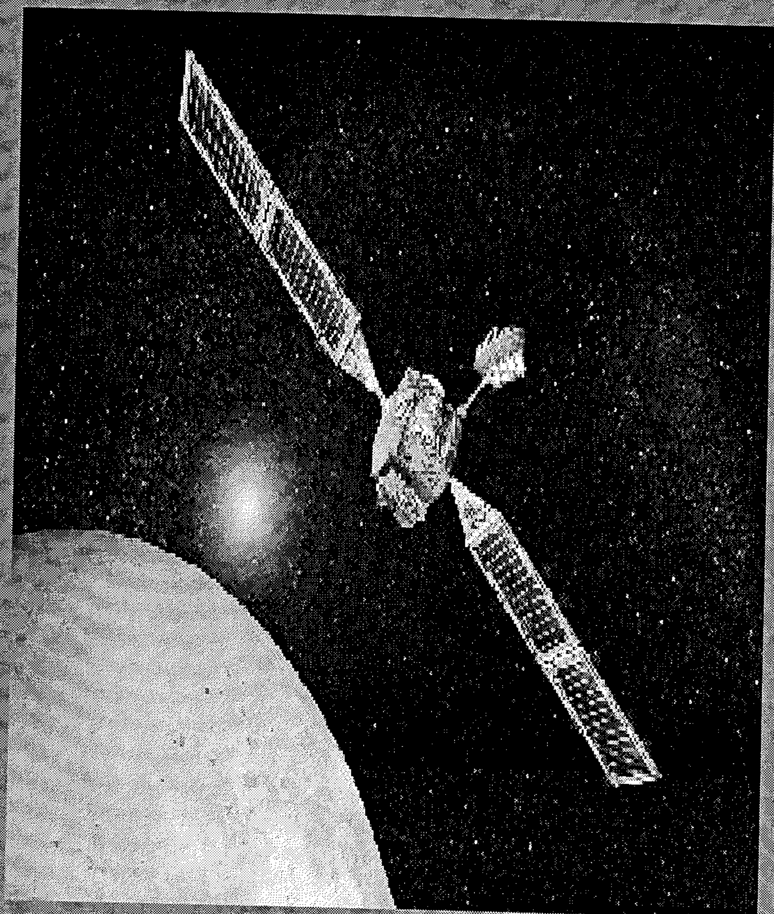
Mars Express: Deep Space Link

- Deep Space Link Frequencies: S and X band
- RF Power: 5W in S-band and 30W in X-band
- Data rate:
  - forward link (S or X band): 125bps
  - return link (S/X band): 10-50kbps (125kbps?)
- Coverage: from Perth 32m and Sardinia 64m (starting from late '05); DSN coverage requested for critical maneuvers
- 1.6m High Gain Antenna

Mars Express: Proximity Link

- Proximity Link Frequency: UHF
- RF Power: 5 or 10W
- Data Rates:
  - forward link at 2, 4, 8kbps
  - return link at 2, 4, 8, 16, 32, 64, 128kbps
- Polarization: RHCP
- Modulation: PCM/Bi-Phase/PM with residual carrier
- Coding: uncoded or (7,1/2)
- Antennas: Dual Patch

Nozomi

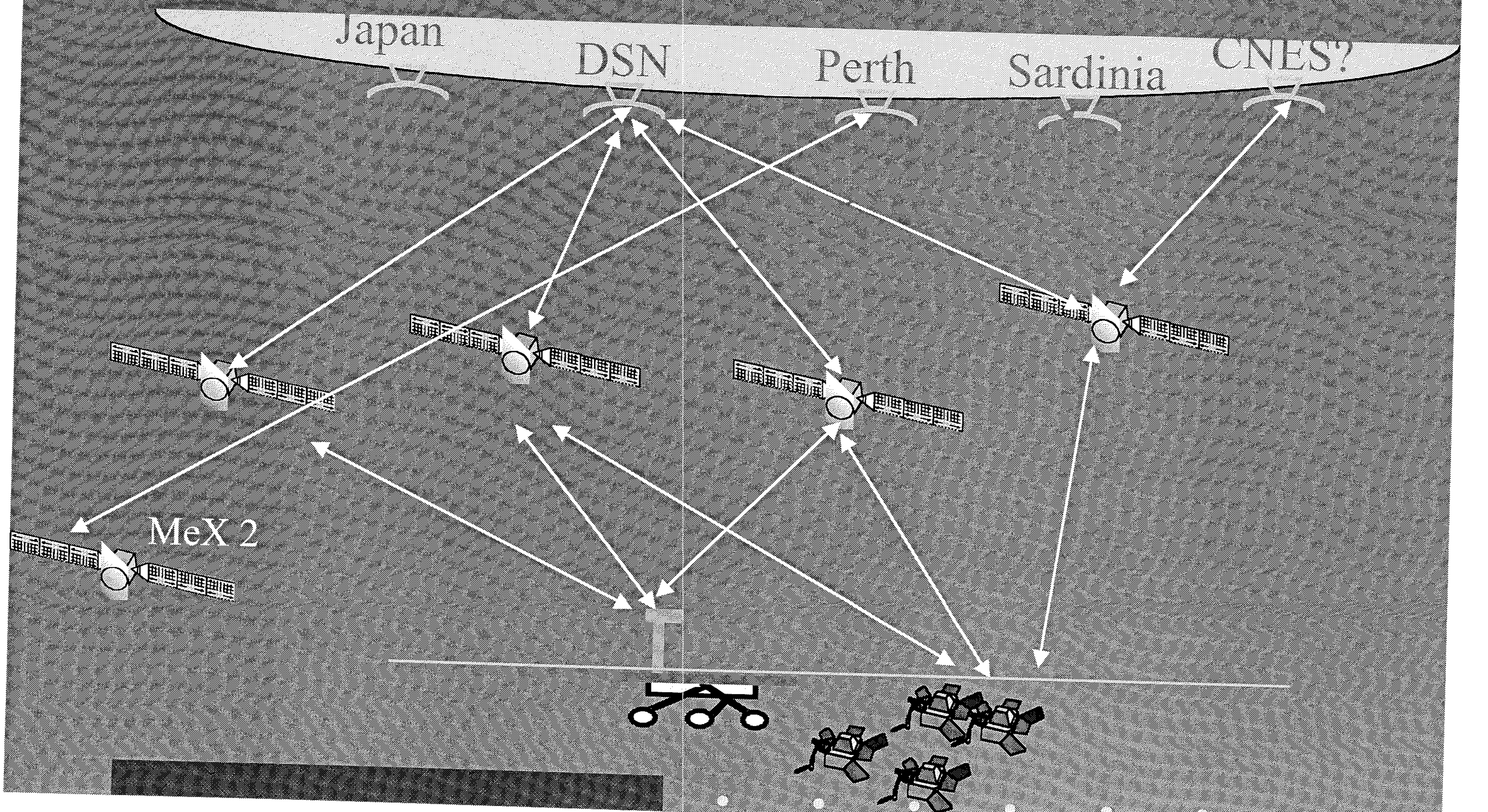


- Primary mission: Jan 04-Nov 06
- Extended Mission: Nov 06- Jan 09
- Orbit: highly elliptical
  - apoapsis = 50000Km
  - periapsis (initial) = 300Km
    periapsis (final) = 150Km
  - orbital period = 38.5h
  - inclination = 170deg

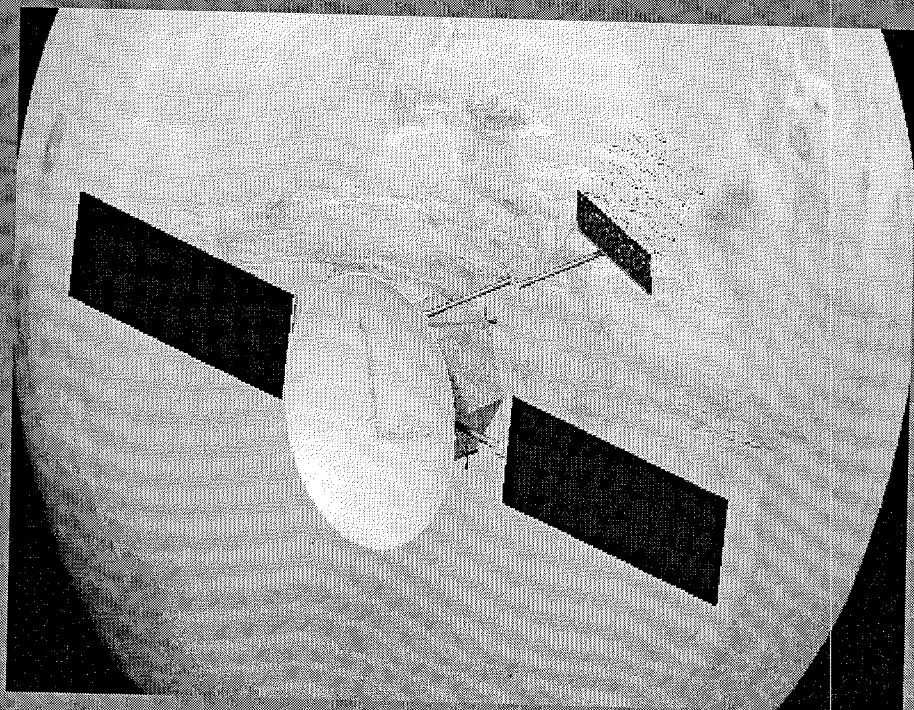
Nozomi: Deep Space Link

- Deep Space Link Frequencies: S and X band
- RF Power: 2.5W
- Telemetry rates: 2.048 - 32.768kbps
- Coverage: continuos during its primary mission using DSN 34m or 70m (Goldstone and Madrid) and a japanese ground station
- 1.6m High Gain Antenna

Telecom Scenario 2006-2009



Mars Reconnaissance Orbiter



- Primary mission: 3 Martian years
- Extended Mission: 2 Martian years
- Orbit: polar and sun-synchronous
  - Apoapsis: 400Km
  - Periapsis: 200Km

MRO: Proximity Link

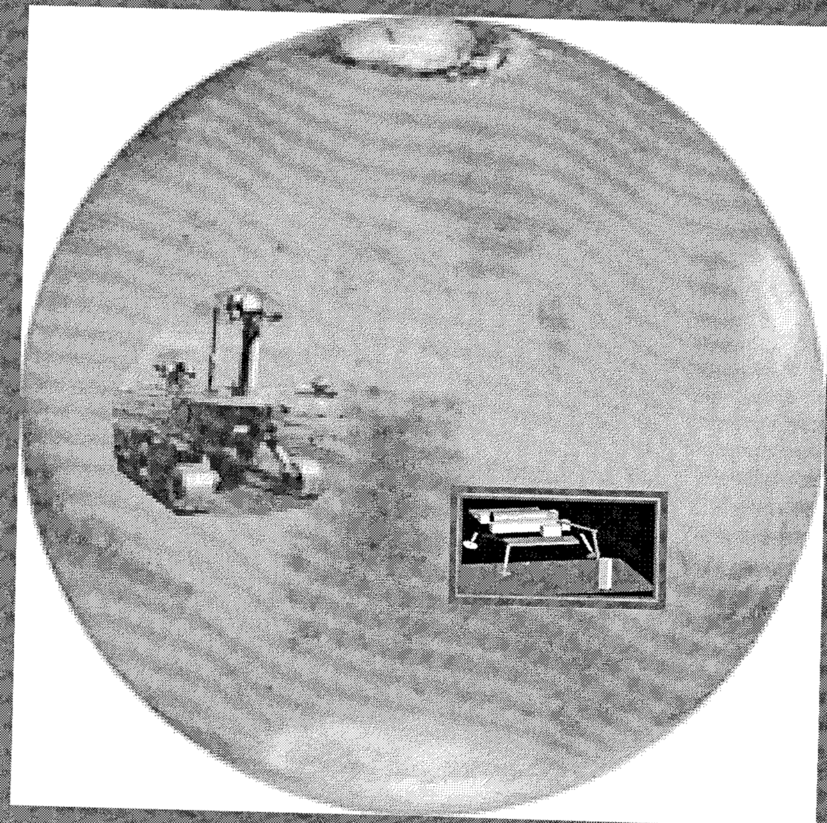
- Proximity Link frequencies: UHF (390-405MHz and 435-450MHz sub-bands) X band
- RF Power: 1-10W (selectable)
- Return data rates: 1, 2, … 512Kbps
- Polarization: RHCP
- Antennas (mounted on a 2m boom):
  - at UHF: 2 low omnidirectional (1 nadir, 1 zenit looking) and 1 medium gain
  - at X band: 1 nadir-looking low gain

MRO: Deep Space Link

- Deep Space Link Frequency: X band
- Power: 100W TWTA
- Return data rate: 350kbps – 6Mbps
- Near Continuous Availability on DSN 34m or 70m antennas
- 2.5 m High Gain Antenna

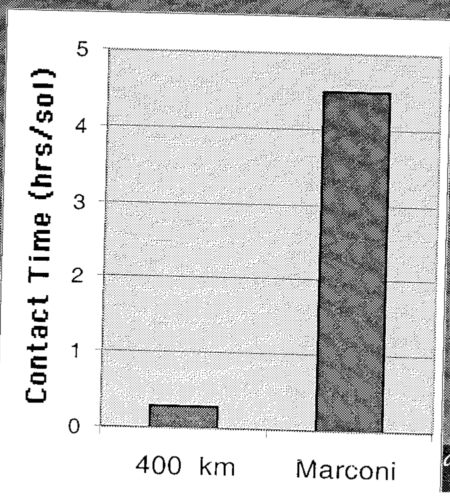
In Situ Science : 2009 Smart Lander

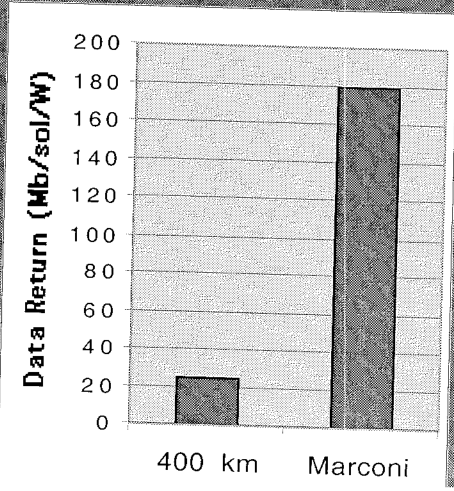
- DeeDri :Deep Drill is a drill capable to acquire and handle samples as well as perform science on the surface and within the hole
- IPSE : Italian Package for Science Experiments is a near autonomous miniaturised laboratory capable to house, control and serve a set of instruments in situ science
- Possible participation to Netlanders

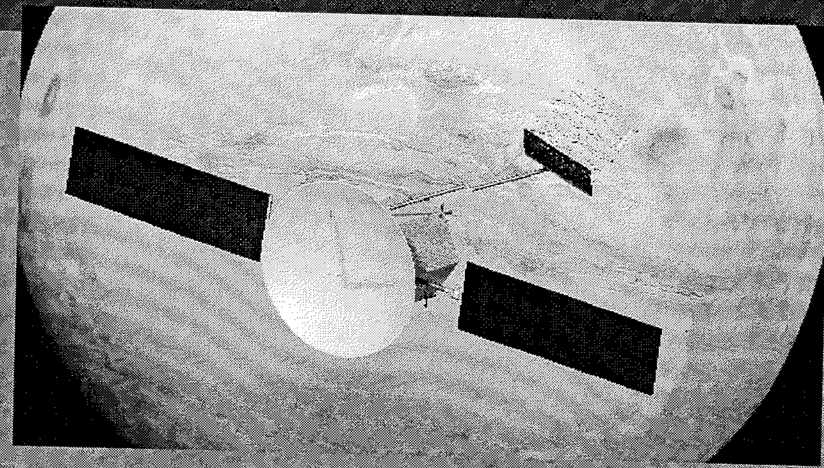


2007 Marconi Comm/Nav Orbiter

- **First dedicated Mars telecommunications and navigation orbiter**
  - Mid-altitude orbit optimized for comm/nav role, improving performance relative to low-altitude science orbiters
  - Will provide comm (EDL and surface relay) and nav (approach nav, surface position, orbital rendezvous) services to other elements of Mars program







- **Joint ASI/NASA mission**
  - ASI (Italy) provides:
    - Spacecraft
    - Assembly Test Launch Operations
    - Spacecraft flight operations
  - NASA provides:
    - Prox link comm/nav payload
    - Deep space-specific engineering support
    - Prox link service ops

NASA's Telecommunications Strategy for Mars Exploration

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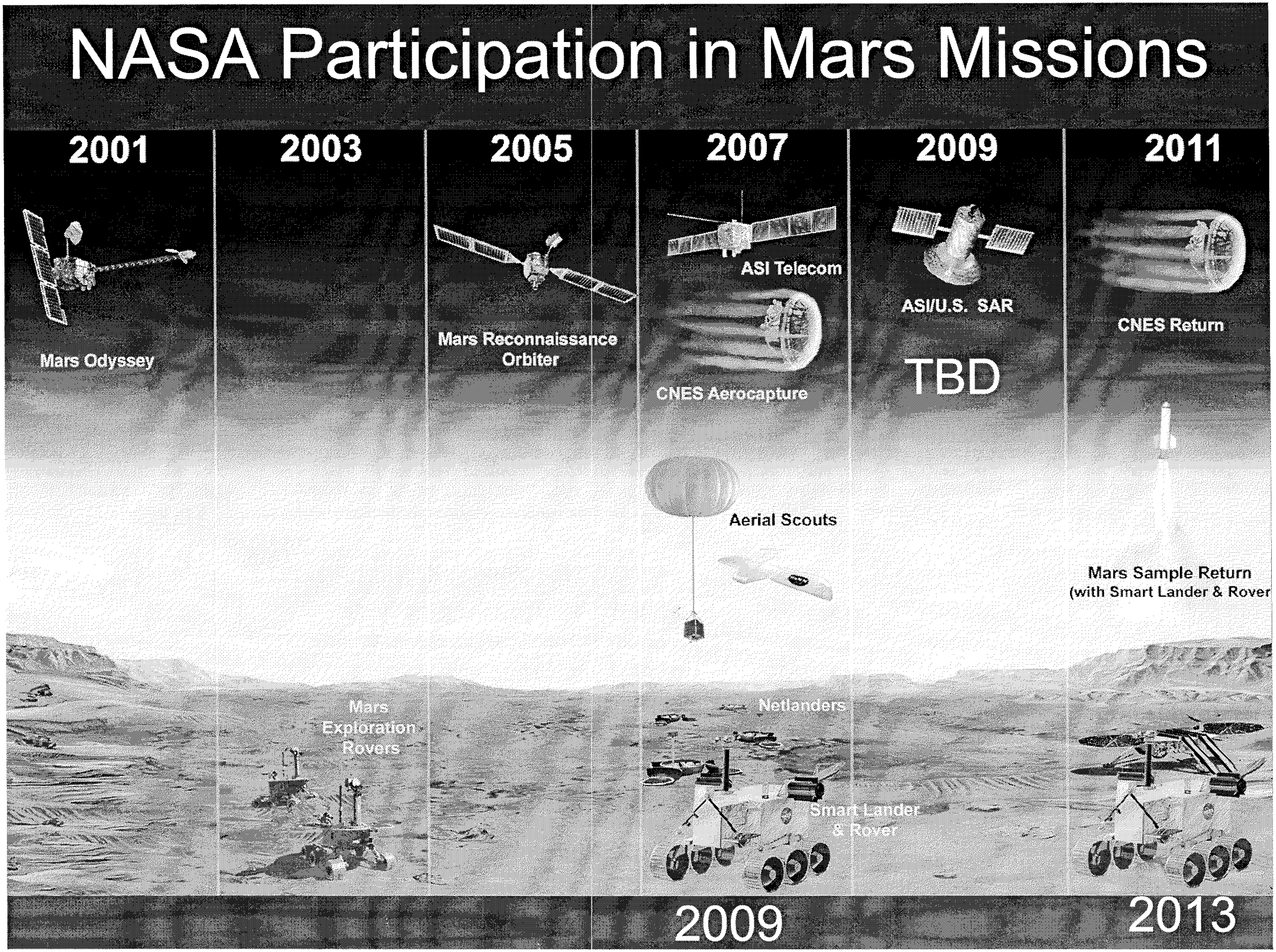
Rolf C. Hastrup, Thomas C. Jedrey, Greg J. Kazz
Jet Propulsion Laboratory, California Institute of Technology,
Pasadena, CA 91109, USA

Outline

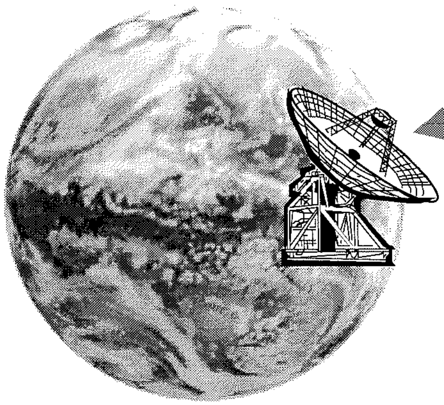
- **Program Overview**
- **Capability Trades**
  - Telecommunications
  - Data Management/Data Transport
- **Electra - A Standardized Proximity Link Communication/Navigation/Time transfer Payload**
- **Communications Protocols**
- **Summary**

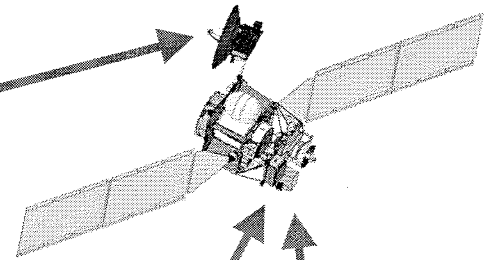

NASA Participation in Mars Missions
2001
2003
2005
2007
2009
2011
Mars Odyssey
Mars Reconnaissance Orbiter
ASI Telecom
CNES Aerocapture
ASI/U.S. SAR
TBD
CNES Return
Aerial Scouts
Mars Sample Return
(with Smart Lander & Rover
Mars Exploration Rovers
Netlanders
Smart Lander & Rover
2009
2013

Program Drivers on Comm/Nav/Timing Infrastructure

- Increased science data return (e.g., for multi-spectral surface pancam imagery)
- Complexity of Mars Sample Return surface operations, with the resulting need for frequent command cycles and rapid, low-latency engineering data return to support operations planning
- Robust, high-accuracy radio-based approach navigation (e.g., ~<1 km entry knowledge for aerocapture or precision landing)
- Capture of real time engineering telemetry during critical events such as EDL, aeromaneuvering, MAV launch, etc., for feed-forward fault diagnosis in the event of anomaly
- Energy-efficient relay telecommunications for energy- and mass-constrained scout-class missions
- Radio tracking of orbiting sample canister to support in-orbit sample rendezvous
- Surface position determination to support long-range rover navigation

Mars Telecommunications: Representative Capabilities





Orbiter Direct-to-Earth Link

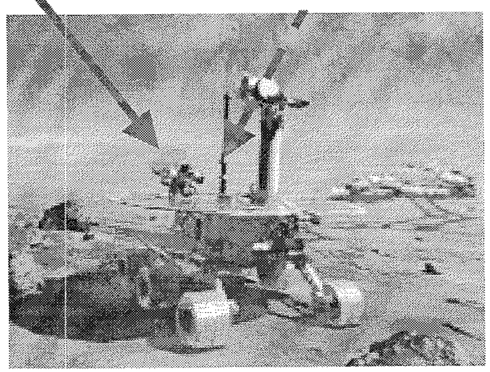
- **10 kbps - 1 Mbps to 34m @ 2.7 AU**
- **Example: MGS**
  - 25 kbps
  - 1.5 m HGA
  - 25 W TWTA

Lander Relay Link

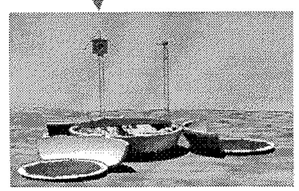
- **100 kbps - 1 Mbps**
- **Example: MER**
  - 128 kbps
  - Omni UHF antenna
  - 10 W SSPA

Large Lander Direct-to-Earth Link

- **1 kbps - 10 kbps to 70m @ 2.7 AU**
- **Example: MER**
  - 2 kbps
  - 28 cm HGA
  - 15 W SSPA

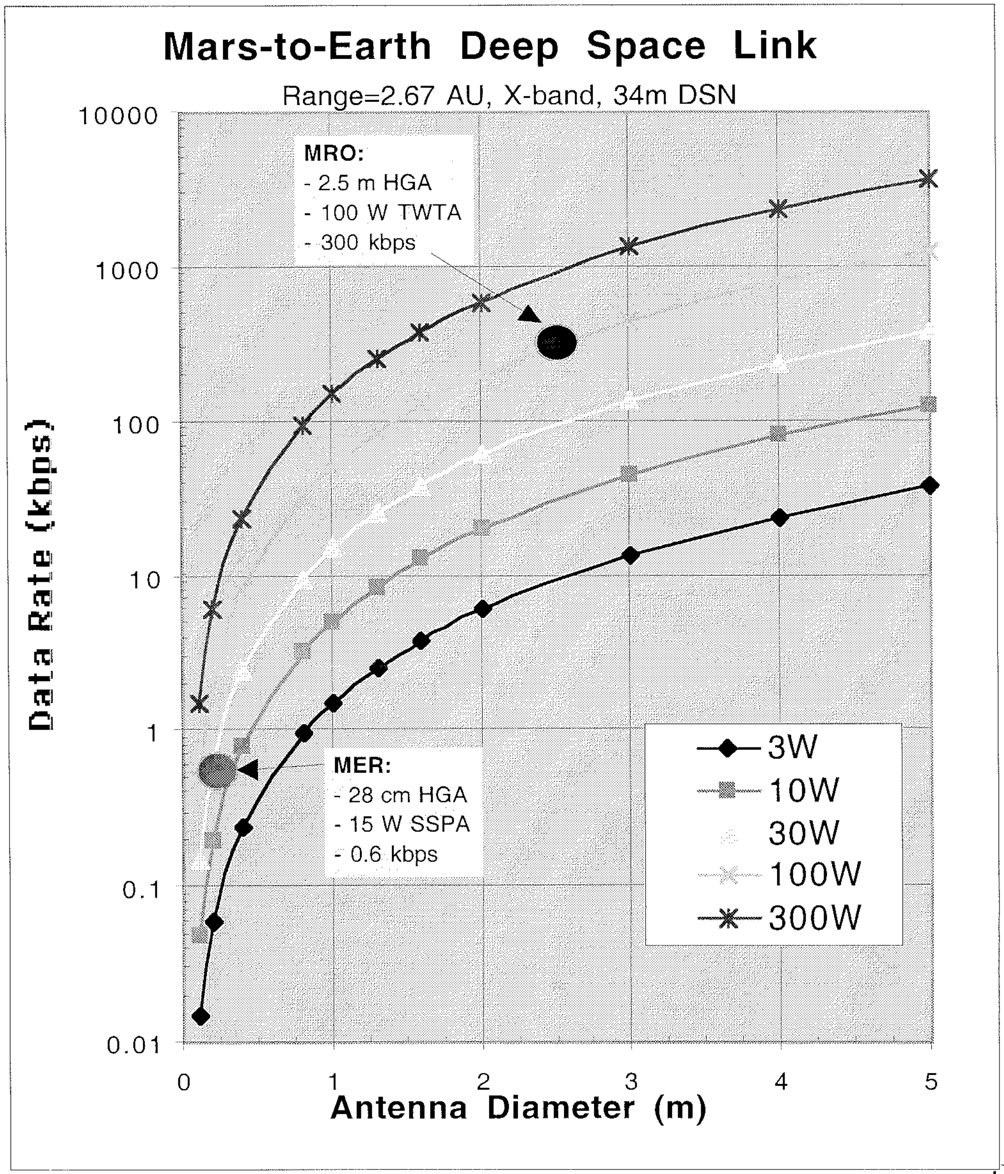


No DTE capab ility for Scout-class landers

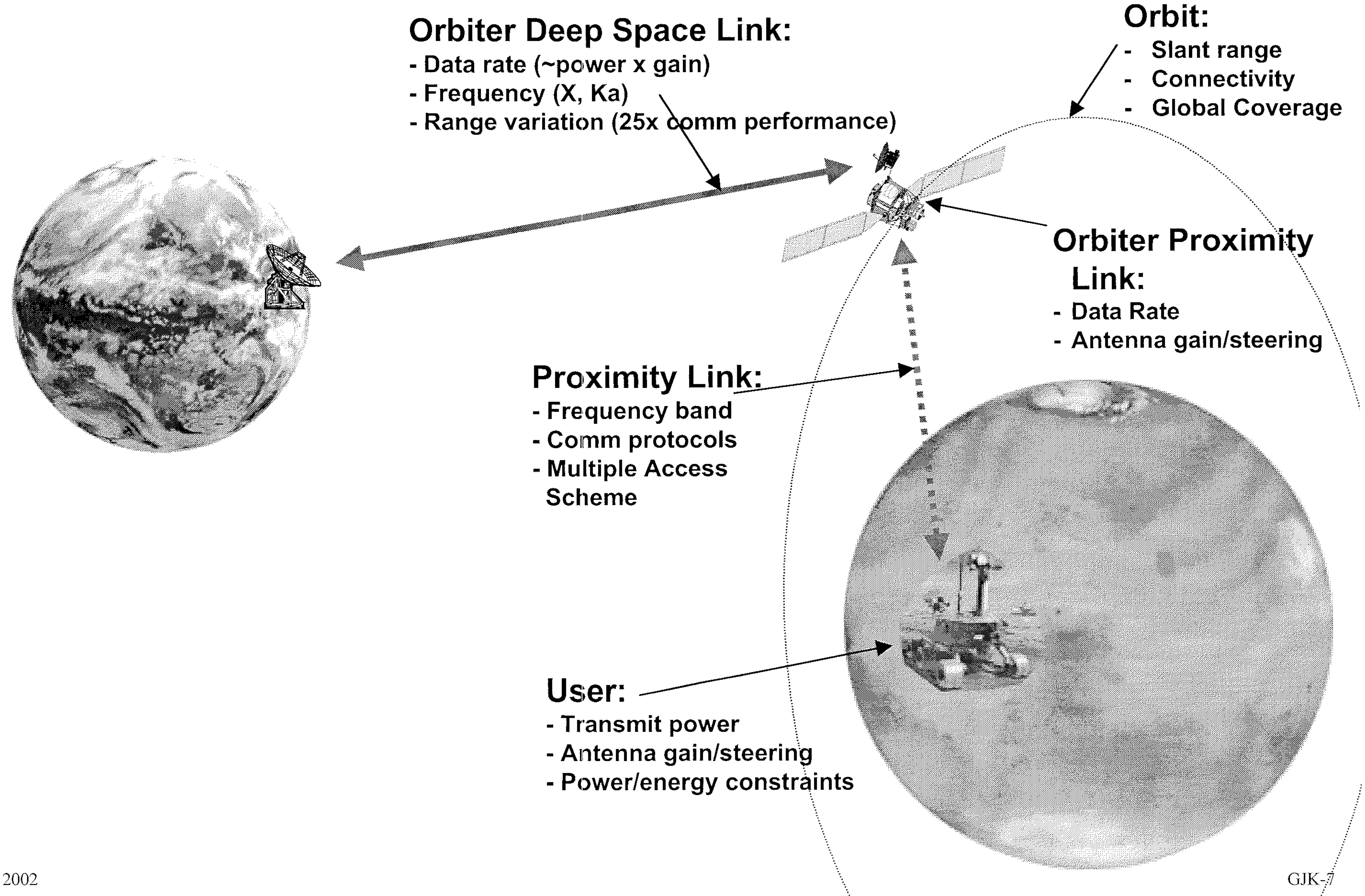


Direct-to-Earth Communications

- **Keys to increased DTE link capability:**
  - Transmit power
  - Transmit aperture
  - Frequency (Ka-band offers ~4x improvement over X-band
  - Earth receive aperture (70m offers ~4x improvement over 34m)
- ***Mass, power constraints imply landed DTE capability will always fall well below orbital DTE capability***



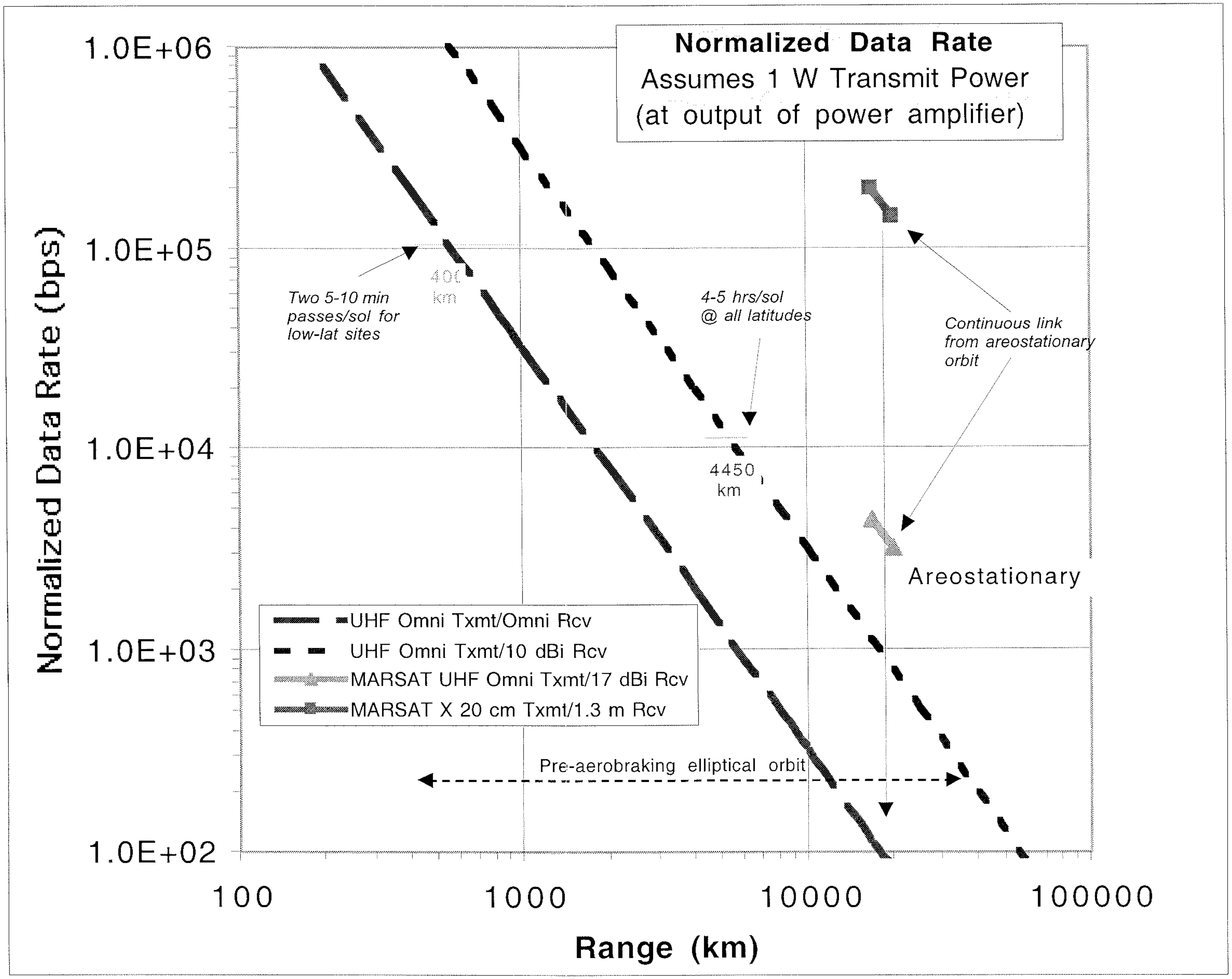
Key Aspects of Relay Communications



Proximity Link Characterisitics

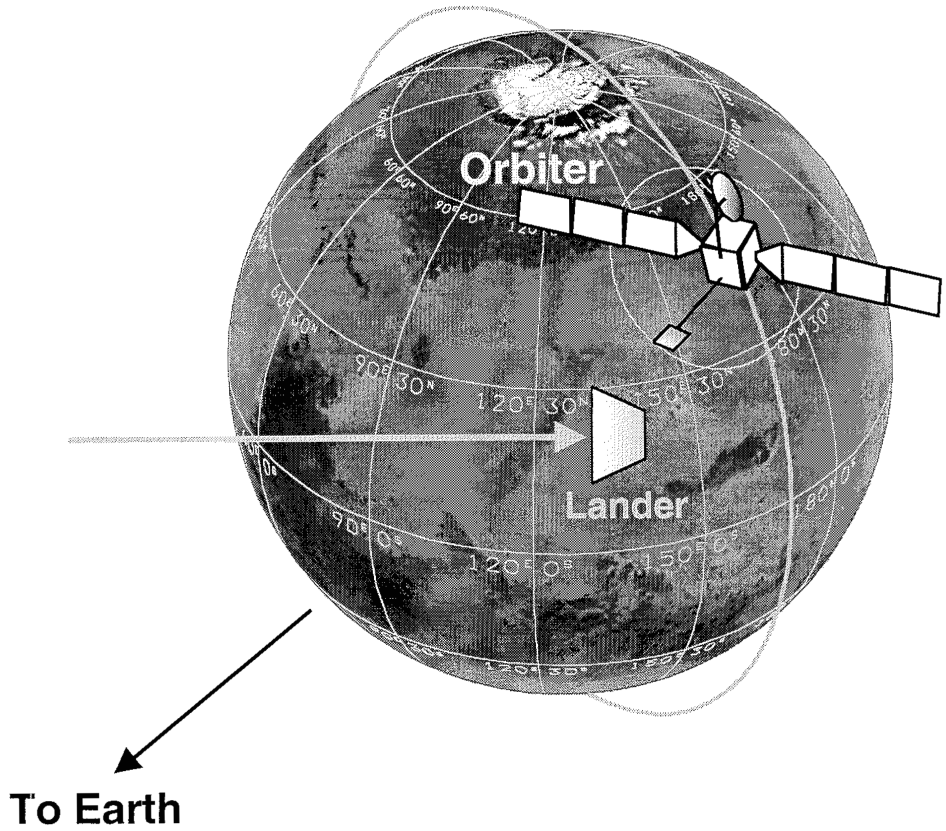
- **Omni-to-omni links**
  - Simple ops for lander and orbiter
  - Link performance scales as $1/\text{freq}^2$
  - Current ~400 MHz UHF band represents balance between link performance and RF component size
- **Omni-to-directional links**
  - Increased orbiter antenna gain can significantly improve link performance
  - To first order, for fixed orbiter aperture size, link performance is frequency-independent
  - However, orbiter antenna pointing requirements scale with frequency
- **Directional-to-directional links**
  - Opens possibility for very high link performance, event over long slant-range links
  - Requires antenna pointing at both ends of link
  - Link performance scales as freq^2

Proximity Link Communications



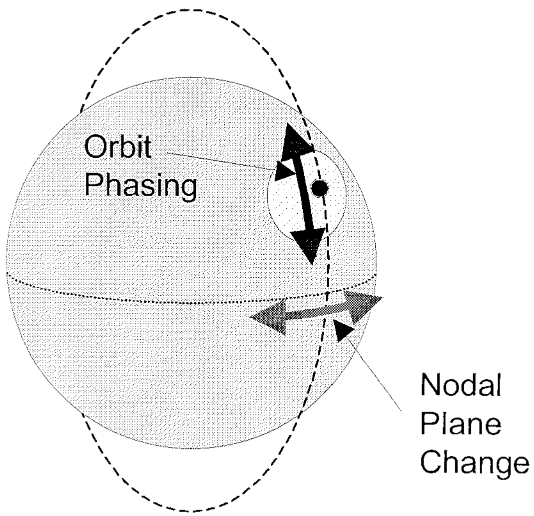
Critical Event Communications

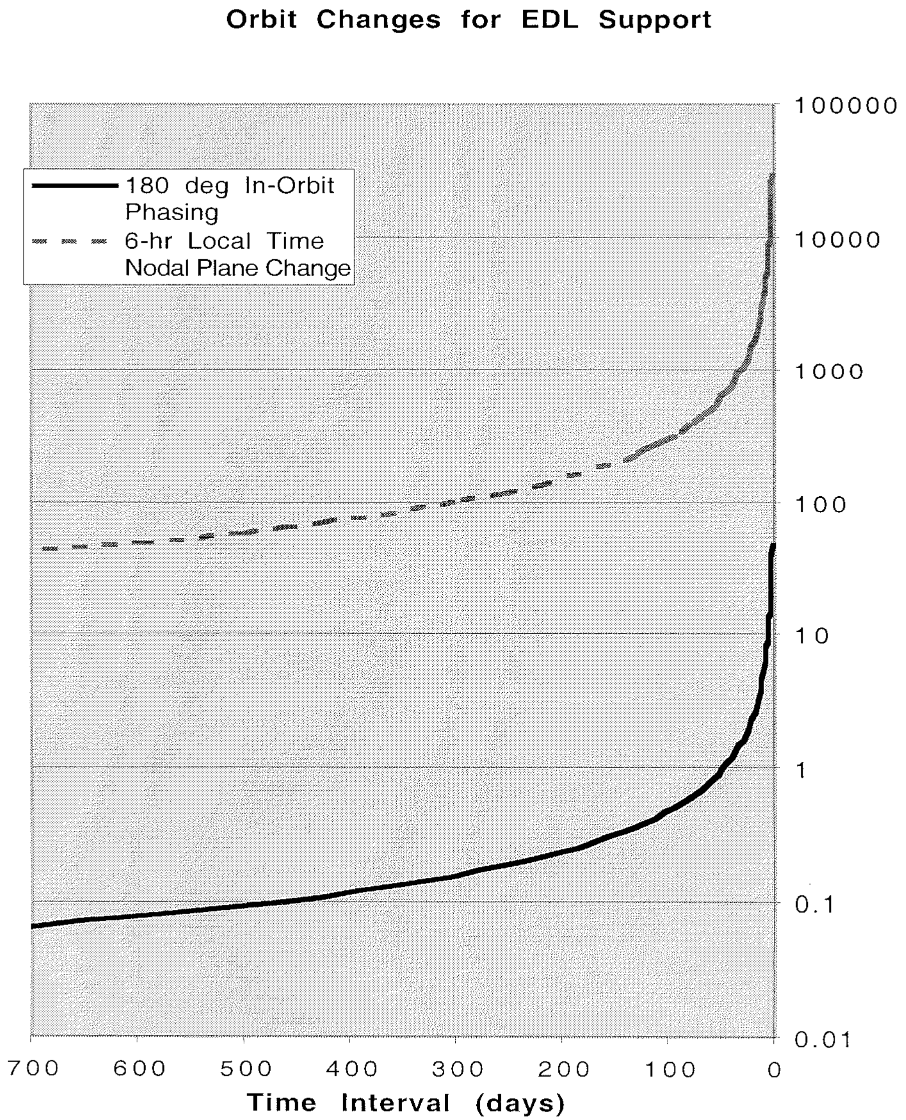
- **Program policy is to ensure realtime communications for critical mission events**
  - Entry, Descent, and Landing
  - Mars Ascent Vehicle Launch
  - Aerocapture MOI
- **Options:**
  - DTE "semaphores" can provide ~ 1 bps capability
  - High-rate prox link (will be required to characterize more complex 2nd-gen systems)
    - Infrastructure orbiters
    - Converted cruise stage
    - Black box



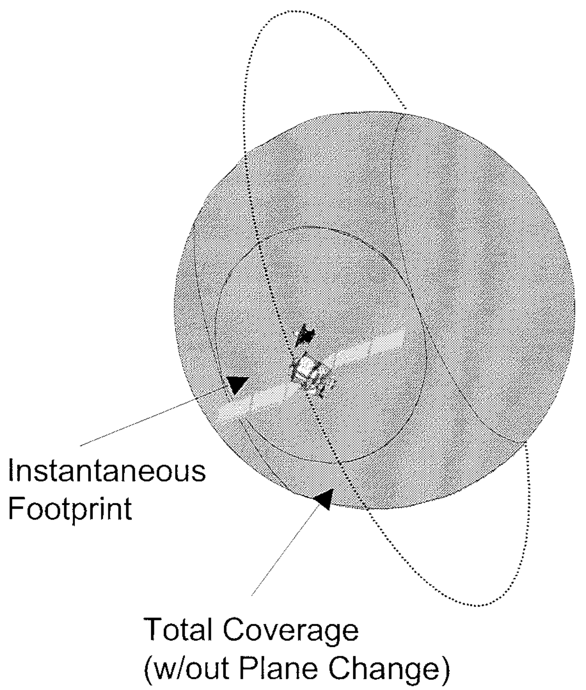
Orbital Changes to Support EDL Communications

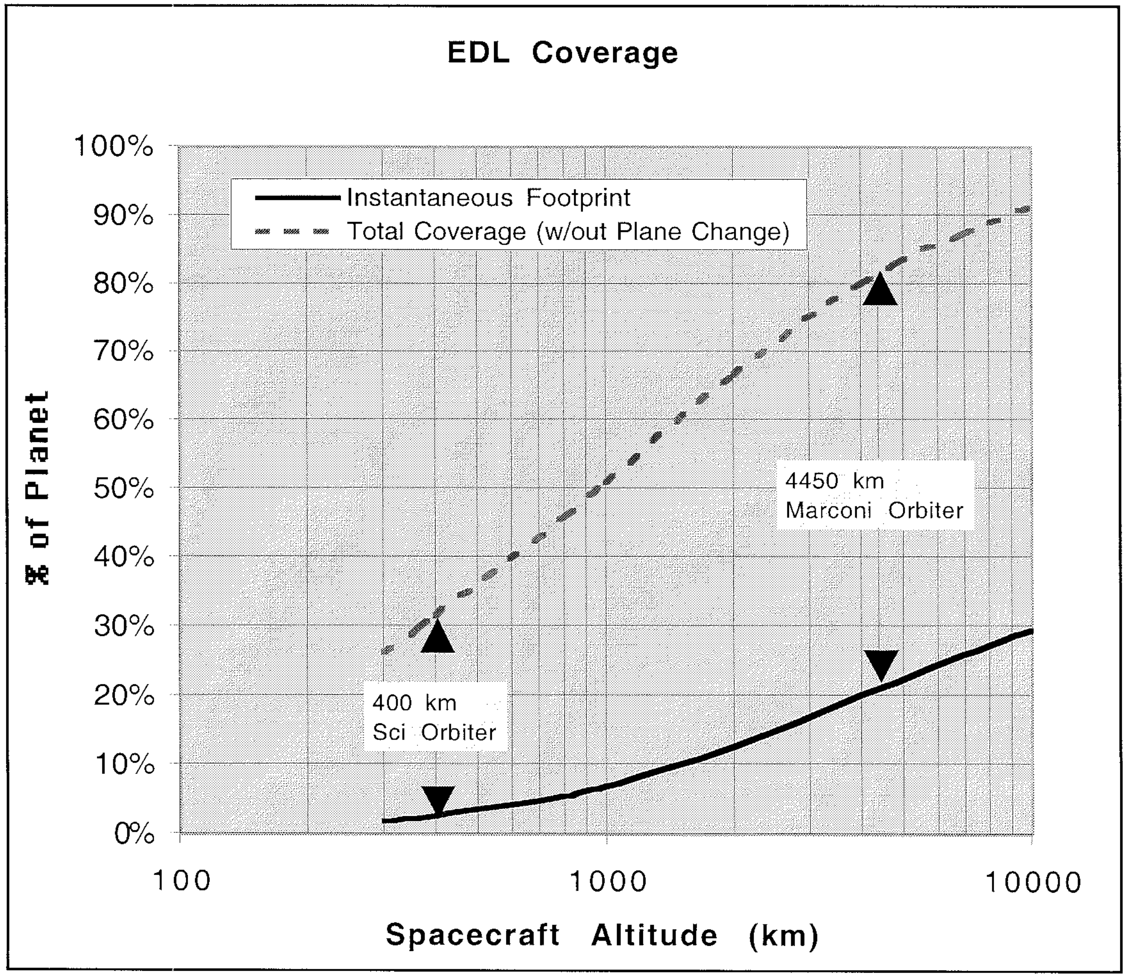
- **Use of low-altitude science orbiter for EDL comm relay requires orbit adjustment to ensure EDL visibility**
- **Preliminary analysis of ΔV partial derivatives**
  - In-plane orbit phasing: ~0.26 m/s per deg/day
  - Nodal plane change: ~326 m/s per deg/day





EDL Coverage

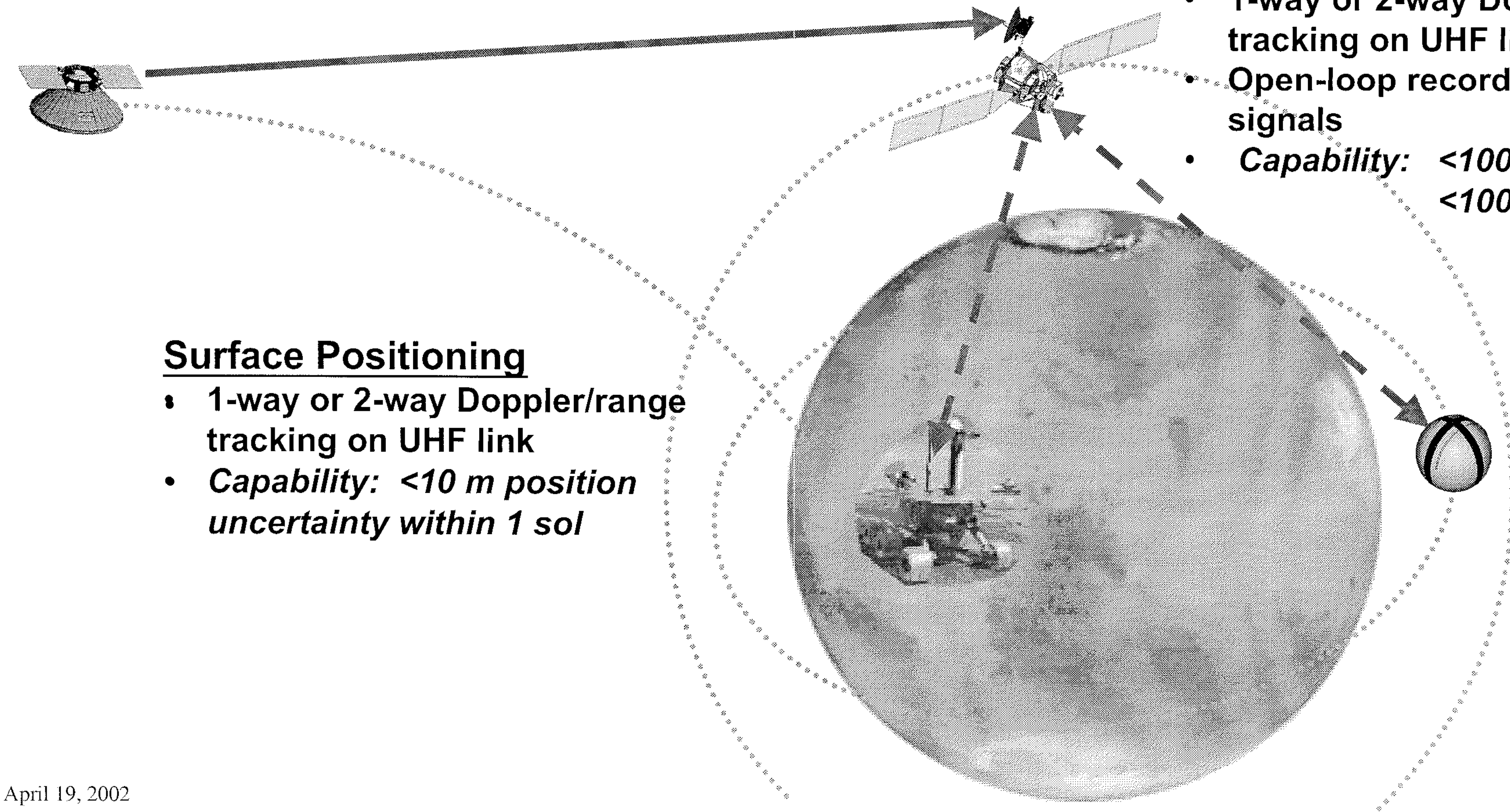




Key Aspects of Relay Navigation

Precision Approach Navigation
- X-band Doppler on HGA link between approach s/c and orbiter
- *Capability: <0.5 km B-plane error @ E-1 day*

Orbiting Sample Canister Tracking
- 1-way or 2-way Doppler tracking on UHF link
- Open-loop recording for weak signals
- *Capability: <100 km 1-way*
  <100 m 2-way



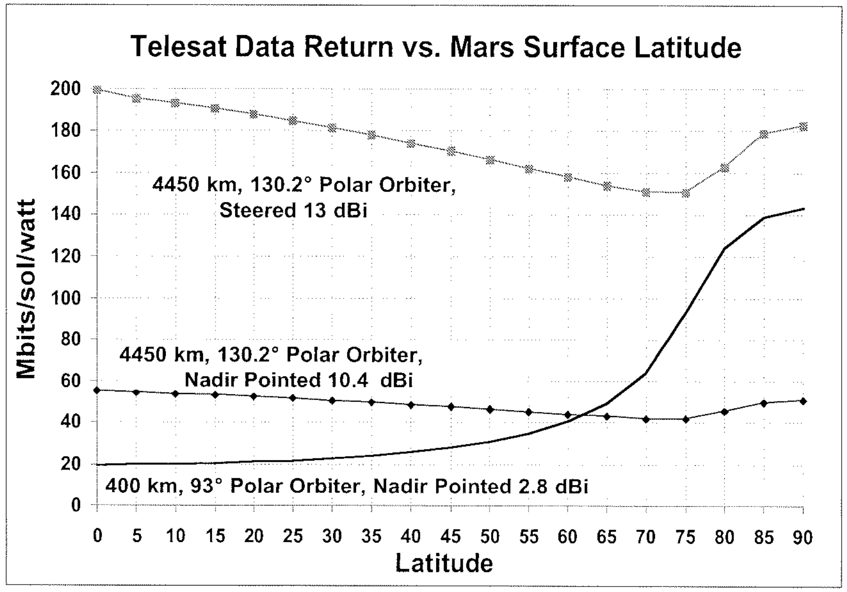
Surface Positioning
- 1-way or 2-way Doppler/range tracking on UHF link
- *Capability: <10 m position uncertainty within 1 sol*

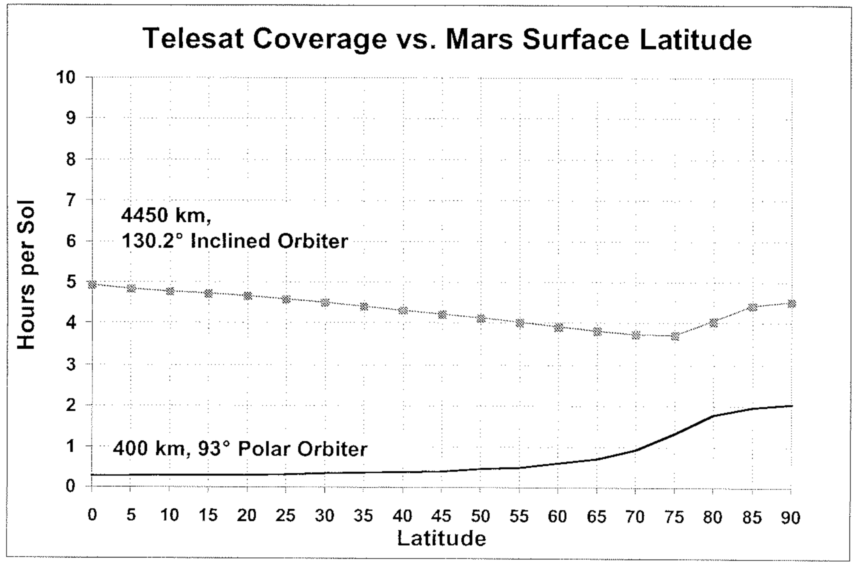
Trade Space: Relay Orbits

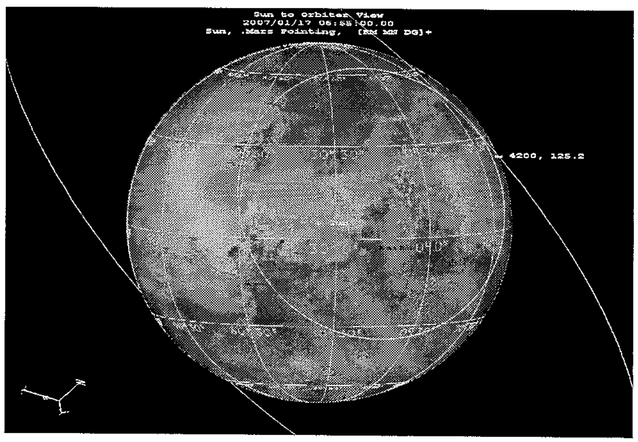
Orbit	Pros	Cons
Low-altitude polar	Global coverage; low slant-range for energy-efficient relay comm, even with simple omni antennas	Very limited connectivity, particularly in equatorial band
Low-altitude equatorial	Frequent contact to equatorial region (can complement polar orbiters); low slant range	No coverage to mid-lat and polar regions
Mid-altitude (e.g., alt = 4450 km, incl = 130 deg)	Global coverage with uniform connectivity from pole to pole; longer and more frequent pass durations	Larger slant range (can be compensated to some extent by increasing orbiter antenna gain)
Areostationary (alt = 17,000 km)	Continuous contact to one region of planet	Large slant range; hi-rate links will require directivity from surface user; no global coverage
"High-Noon" elliptical orbits	Several orbits exist with precession such that apoapse is fixed near local noon, resulting in long daytime passes	Large slant range at apoapse; hi-rate links will require directivity from surface user; variable slant range over orbit increases ops complexity

Mid-Altitude Orbiters

- **4450 km altitude provides increased coverage**
  - Large ground track
  - 4-5 hrs contact per sol, nearly uniform in latitude
  - Multi-Gb/sol with steered orbiter antenna







Areostationary and Highly Elliptical Orbiters

- **Areostationary**
  - 17,000 km altitude
  - Continuous view of one region of planet (~25% of planet centered about sub-satellite point; no view of polar regions)
  - High-rate (~1 Mbps) continuous relay to Earth with directional surface antenna (satellite at fixed point on sky w.r.t. surface user)
  - Lower-rate (~10 kbps) continuous relay to Earth with simple omni surface antenna
- **HEO**
  - Several "sun-sync" orbits exist with apoapse at a fixed local time (e.g., local noon); long daytime passes
  - Large slant range at apoapse -> similar link considerations as for areo: directional surface antenna req'd for high rate (but now satellite moves on sky w.r.t. surface user)

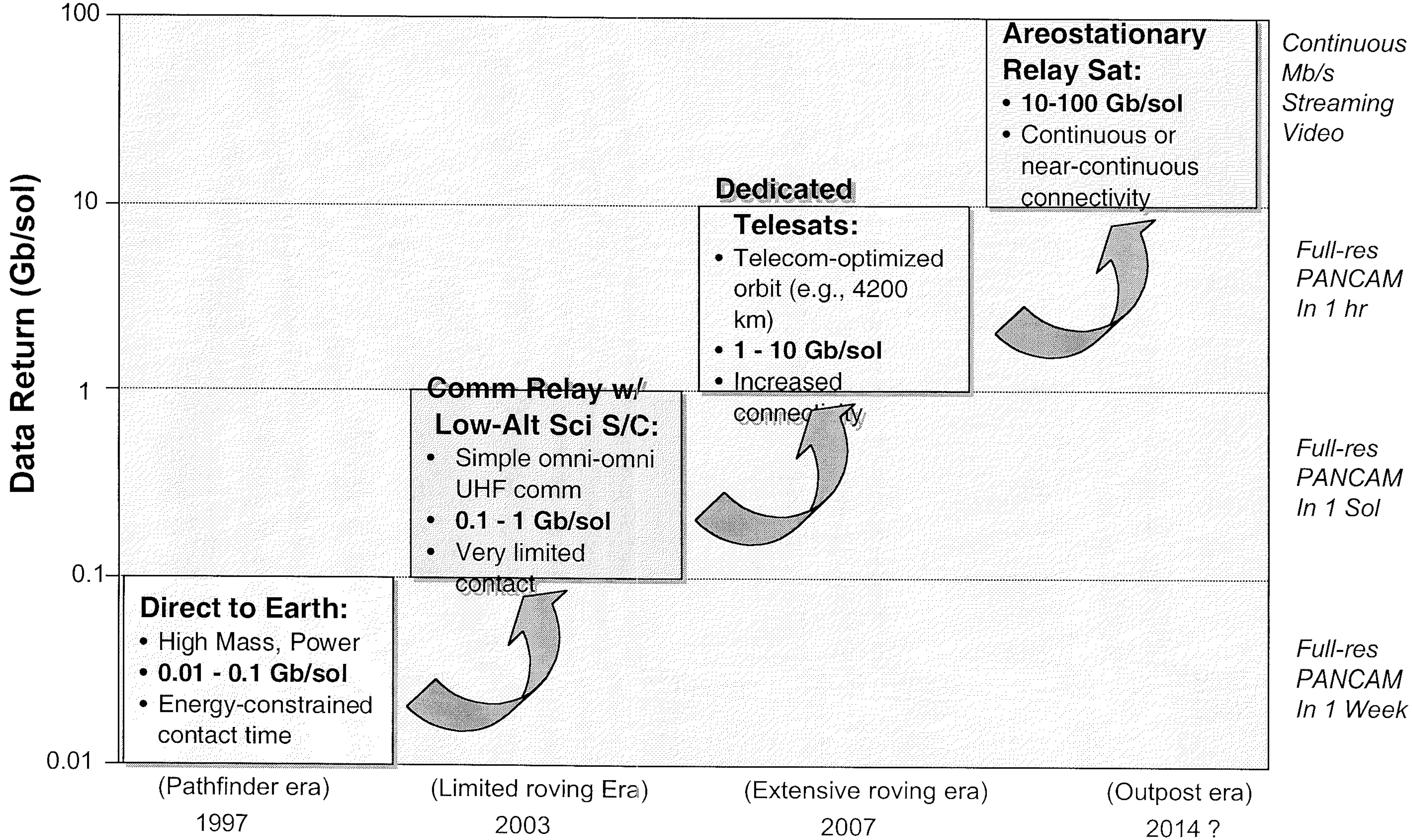
Electra Proximity Link Payload

- **Effort is underway to develop a next-generation standardized Mars proximity link payload**
  - To be flown on all Mars orbiters, starting with MRO'05 - provides *de facto* interoperability and enables gradual implementation of Mars orbital comm/nav/time infrastructure at low incremental cost
  - Flight reconfigurable/reprogrammable over long mission lifetime
  - Greater flexibility (wider range of supported data rates; swappable txmt/rcv bands, multi-channel operation)
  - Improved navigation/timing performance
  - Improved performance (coding, low-loss half-duplex mode, increased PA efficiency, ...)
  - Modularity to allow scaling for low-mass lander/scout applications
  - Portability to facilitate integration with variety of orbiters
  - Self-contained relay functionality (including relay data accountability) for improved testability

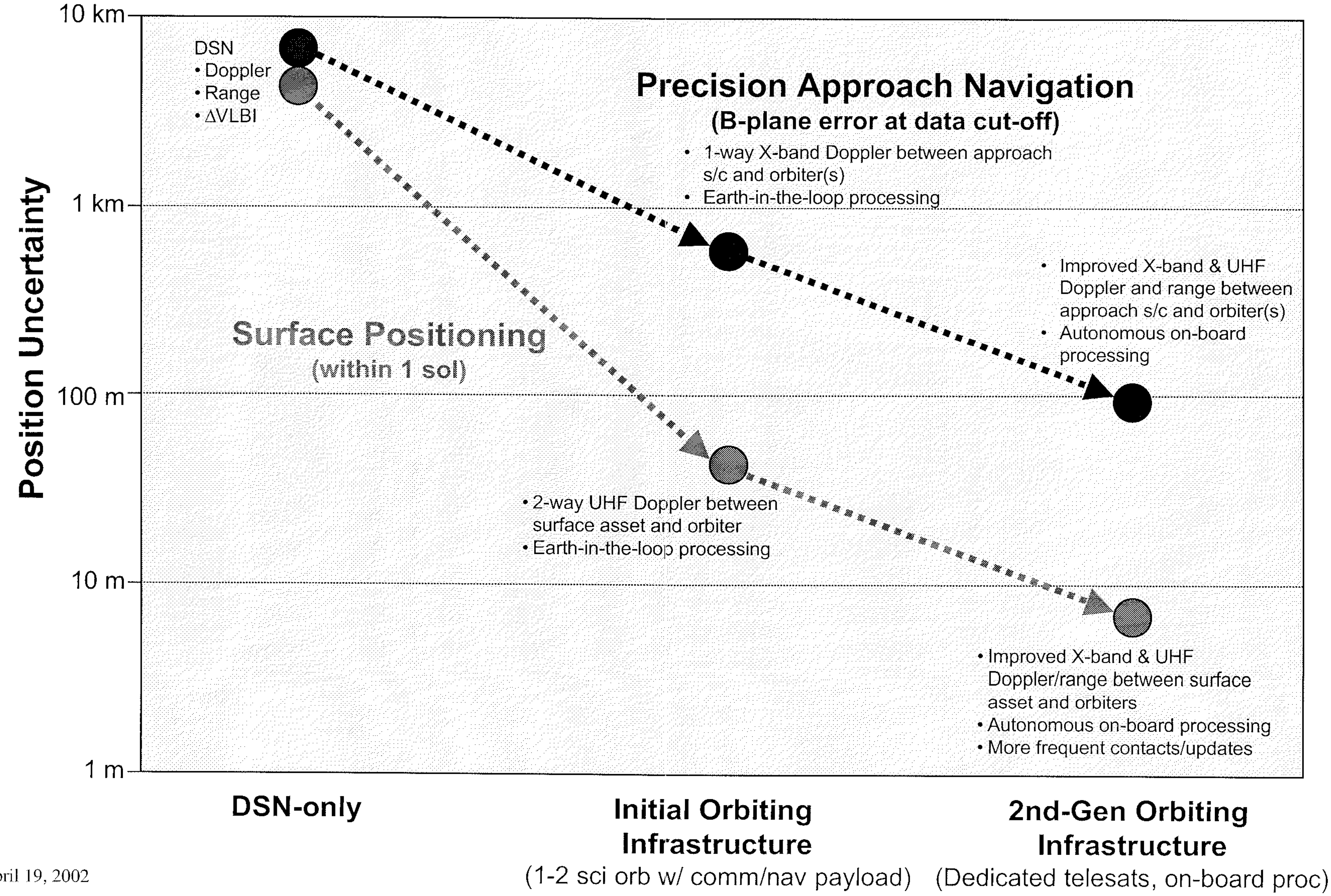
Protocols

- **CCSDS Proximity-1 Space Link Protocol**
  - Provides standards for the physical and data link layers for Mars proximity communications
  - First implementation on Mars Odyssey
  - Will be key for achieving interoperability among MER A/B, Beagle 2, Mars Express, Odyssey and missions beyond 2003
- **CCSDS File Delivery Protocol (CFDP)**
  - Provides reliable and expedited end-to-end file delivery
  - Addresses unique aspects of deep space communications
    - Long Round Trip Light Times
    - Intermittent connectivity – non persistent links
    - Transaction based
    - Multi-hop store-and-forward relays
    - Custody transfer to minimize onboard storage requirements
- **Standards on the web at www.ccsds.org**

Evolution of Mars Telecommunications Capability



Evolution of Mars Radio-Based Navigation Capability

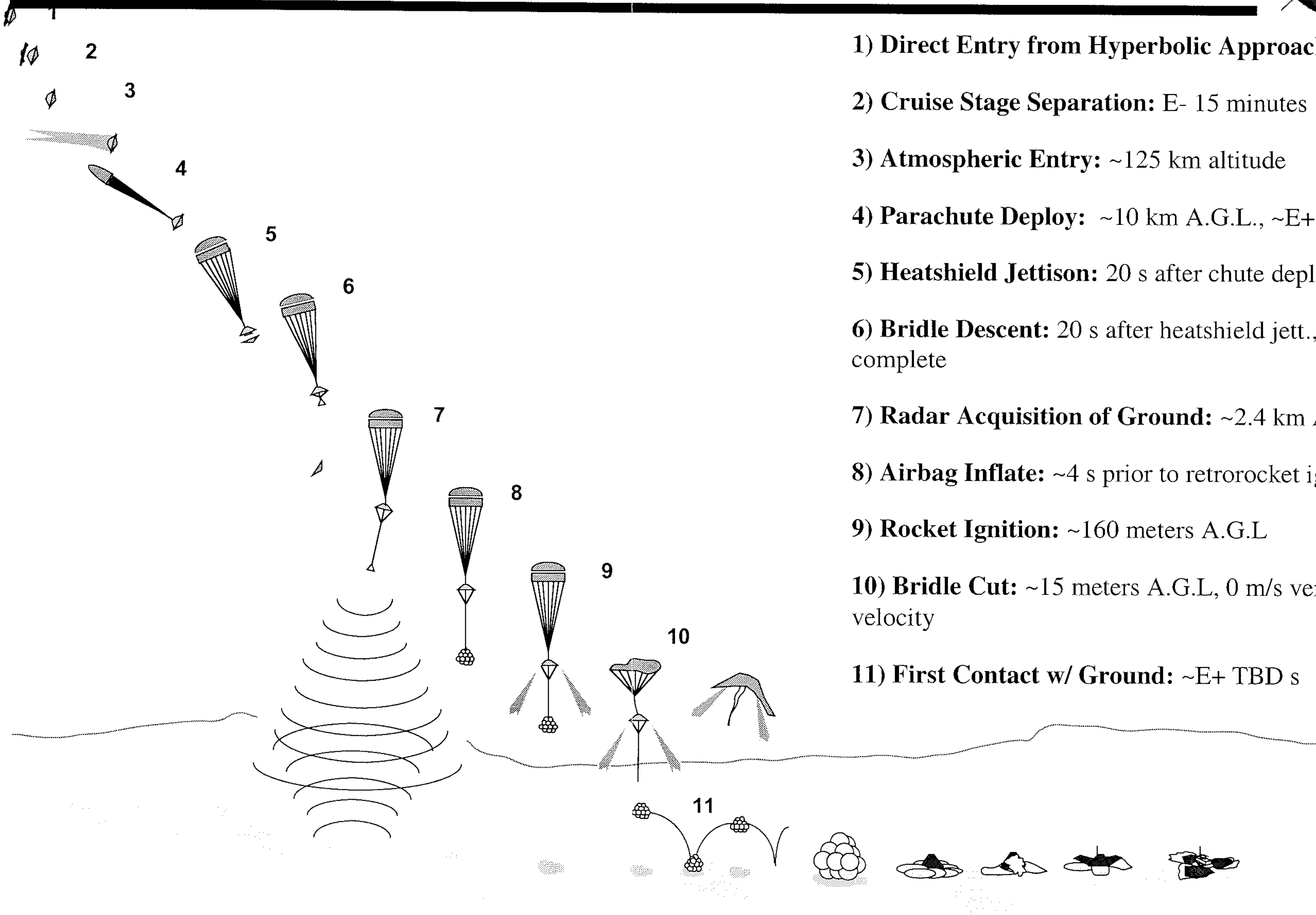


Some Parting Questions...

- **How do we manage and operate a heterogeneous collection of orbital relay spacecraft as an integrated Mars comm/nav infrastructure?**
- **What is the science value of increased bandwidth and connectivity?**
  - How would a continuous high-rate areostationary relay change our surface operations concepts?
- **When is it cost-effective to transition to:**
  - Demand access proximity service concept?
  - On-board radiometric data processing?
  - Higher-frequency directional lander links?
- **How should our proximity link standards evolve?**
  - Physical layer
  - Modulation and coding
  - Higher layers of data management
  - Ultimate interface with IPN vision

A Real-World Example:
MER EDL Communications

EDL Sequence of Events Overview



1) **Direct Entry from Hyperbolic Approach**

2) **Cruise Stage Separation:** E- 15 minutes

3) **Atmospheric Entry:** ~125 km altitude

4) **Parachute Deploy:** ~10 km A.G.L., ~E+ TBD s

5) **Heatshield Jettison:** 20 s after chute deploy

6) **Bridle Descent:** 20 s after heatshield jett., 10 s to complete

7) **Radar Acquisition of Ground:** ~2.4 km A.G.L

8) **Airbag Inflate:** ~4 s prior to retrorocket ignition

9) **Rocket Ignition:** ~160 meters A.G.L

10) **Bridle Cut:** ~15 meters A.G.L, 0 m/s vertical velocity

11) **First Contact w/ Ground:** ~E+ TBD s

EEIS Relay Requirements for Mars Program

formulated for Marsnet

by MM-EEIS group

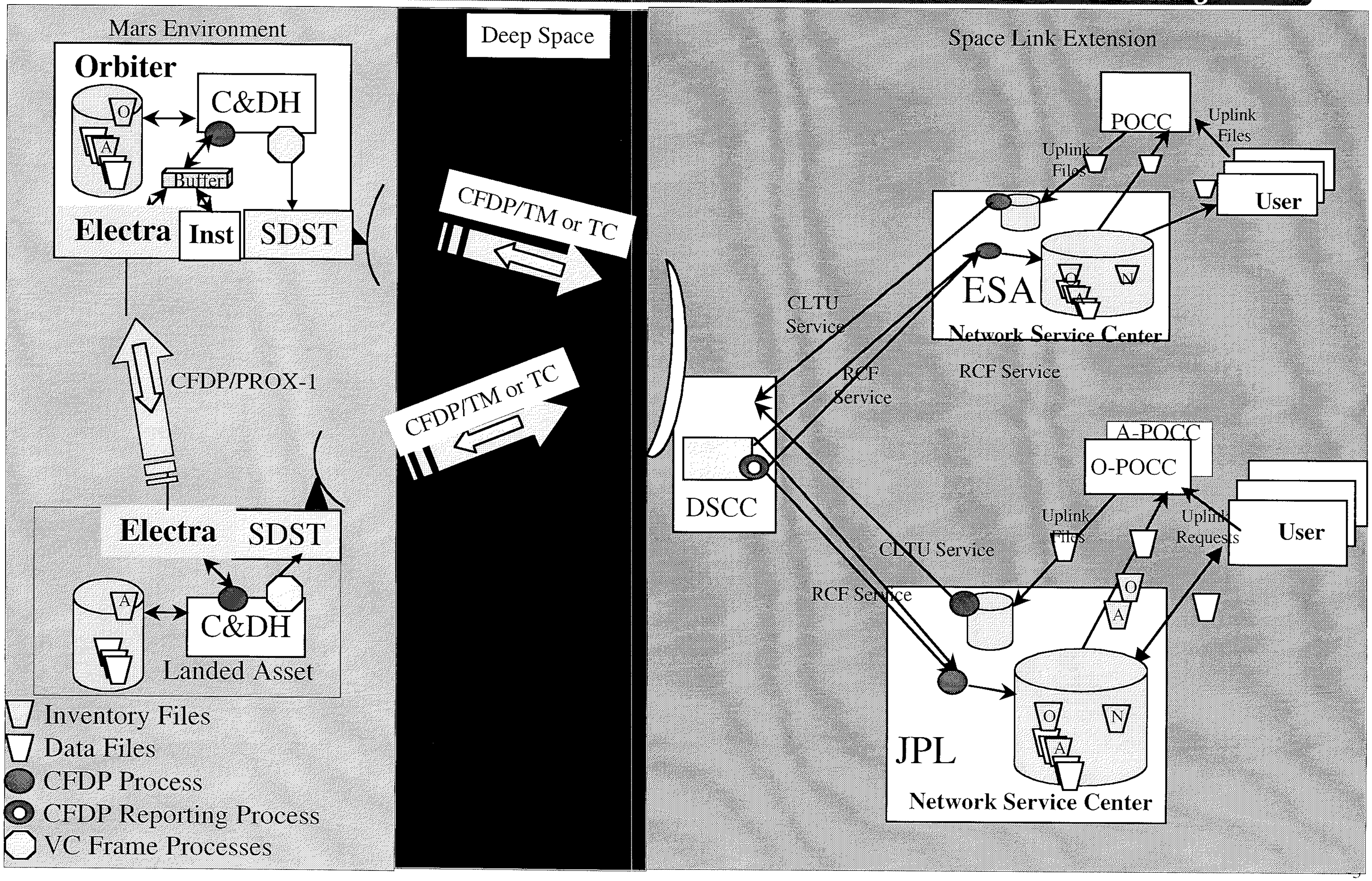
Section 311 at NASA/JPL

What are we trying to accomplish?

- Identify data types, their requirements and data resource management policies
  - Which teams manage what data ?
  - What Data services are provided by Mars Enterprise Elements ?
    - Relay Orbiters
    - IPN-ISD
    - Relay Assets
    - Data service interface requirements
- Identify for each team, and each interface, the performance requirements we need to accomplish to meet the science requirements (level 2) and relay operational objectives
- Identify the End-End data accountability requirements and processes
- Identify the Telemetry Handling and Access requirements
  - including processes and protocols
  - QQCL
- Identify the Timing and Radiometric Service Requirements

Mars Network EEIS Context

Data Flow and Visibility



What Data Types are Required?

- **Science and Engineering Data Products**
  - Products are individual named data entities (Named Data Units)
  - E-E Data Product accounting services shall account for all NDUs created for transfer between Enterprise entities.
  - Each Enterprise Element (S/C, Processing center) shall maintain a Product Inventory
    - Product Inventories shall provide the following:
      - Time of product creation
      - Activity associated with product creation
      - Creator of product
      - Status of Product (delivery and completeness)
      - Other Product attributes TBS
- **Stream Data Units**
  - DTE Link shall use CCSDS Packet Telemetry or AOS frames
  - DFE Links shall use CCSDS Telecommand frames
  - Proximity Links (Mars local communications) shall use CCSDS Proximity-1 Protocol
  - CCSDS Packets are used for source data and application message identification
      - Engineering Telemetry Measurements
      - NDU segments used during transfer (e.g. packets containing CFDP PDUs)
      - Objects for model and or data base updates (e.g. catalogs, state models)

What Data Service Types are Required?

- Identify and quantify data management and delivery services required
  - Forward Services
    - Named Data Unit Delivery Services
    - CLTU Service
  - Return Services
    - Named Data Unit Delivery Services
    - Stream Data Services
- Identify which teams manage what data
- Identify E-E data management requirements
  - Womb to Tomb accounting and delivery status visibility for acquired data products
- Identify for each team, the performance requirements we need to accomplish to meet the science requirements (level 2) and relay operational objectives
- Identify the Telemetry Handling requirements
  - including QQCL performance requirements

Telemetry Data Handling

- Virtual Channels
  - Minimum of two Virtual Channels required for DSN SLE RCF Service
    - real time (on-line) delivery service (could use one VC for delivery to each continents distribution center)
    - off-line (up to 24 hour delay) delivery service
- Accounting (received vs projected)
  - DSN accounts for frames received and delivered to AMMOS/Project's Data Mgt System
  - S/C creates and maintains an Inventory of all NDUs (size, source, activity, creation, other attributes)
    - sends Inventory NDU updates to AMMOS/Project Ops Team for later E-E comparisons
  - AMMOS accounts for packet streams(real time engineering) and Named Data Units products
    - volume comparison with frames received
    - comparison of received NDUs with S/C inventory of NDUs sent
- Three Qualities of Services for NDUs
  - Reliable service requires ground generated ARQ/reports for retransmissions
    - data deleted from storage by custody transfer reports only
  - Best Effort service uses ARQ for a prescribed period
    - data deleted by Custody transfer or after a prescribed period even if not all confirmed
  - Expedited service does not include ARQ (only service available to packet streams)
    - delivers units possibly with deletions
    - data deleted from storage with formulation of telemetry
- Time Correlations
  - Network time accuracies including Time correlation with Landers TBD

Science Products and Relay Data Services-1

Science Products and Relay Data are handled exclusively as NDU(s)

- Orbiter data capture and relay services
  - Minimally the received data are blocked and accounted for as an NDU
    - assumes data are uniquely formatted for instrument unique processing (on-board or on Earth)
      - » Metadata would be created for each NDU
  - Received data that are formatted in CCSDS Packets could be further processed
    - Processing services would be provided by agreement with the Asset/Instrument
      - Packet Services: This service would select packets by their APID for inclusion in a derived NDU(s)
        - Functionality may be needed for different required delivery latencies and/or QOS
        - Metadata would be created for each NDU
      - CFDP Service: This service transformations of the CFDP packets into the NDUs
        - Transaction received metadata is used for each individual transaction NDU received
          - * Name, size, time of creation, other attributes (e.g. destination, priority (time to live), QOS)
        - NDU will be accounted for an E-E basis
          - * Accounting begins with inventory unit created in the originating Asset

Science Products and Relay Data Services-2

Science Products and Relay Data are handled exclusively as NDU(s)

- IPN services
  - Stream accounting is provided for Received Telemetry frames (not for user)
    - Continuous sequences of Frame of matching quality are account for as a block
      - RAF accounting is by number of frames and a duration
      - RCF accounting is by frame sequence number within a VC and the duration
  - Stream accounting is provided for Received Telemetry packets (for user)
      - Packet Services: This service would select packets by their APID for inclusion in a derived NDU
        - Metadata would be created for each NDU
  - NDU Services
      - CFDP Service is the only NDU service provided by IPN:
        - » This service transforms the CFDP packets into the NDUs
        - » Transaction received metadata is used for each individual transaction NDU received
          - * Name, size, time of creation, other attributes (e.g. destination, priority (time to live), QOS)
        - » NDU will be accounted for an E-E basis
          - * Accounting begins with inventory unit created in the originating Asset

SSR Buffer Data Handling Services

- Instrument or Relay data are processed using the same C&DH toolset
  - Unformatted stream data are transformed into units for data management
    - upon completion of "pass" the SSR contents are identified as an NDU
      - non-instrument specific processing could add/extract metadata
        - » time created, instrument, activity, etc
      - instrument/S/C specific processing could transform the data as required
        - » contents would be processed by on-board instrument/ S/C specific processing tools
  - Buffer contains CCSDS Packets
    - Packets could be separated for special processing by APID
      - build telemetry NDUs countaining selected APIDs for real time or off line delivery
    - CFDP Packets/PDUs could be used to translate pass data into multiple NDU
      - each file will carry its own metadata:
        - » File name, size, time of creation, other attribute
        - » routing information (e.g. destination, priority (time to live), QOS)

Data Accountability

- Data Units produced on-board are accounted for from Conception to final Archival or delivery by Mars Network OPS (for projects using relay services)
  - Science teams project activity volumes by instrument
  - Instrument teams manage selected data for on-board processing
  - MOS Data management monitors all data activities
    - accounts for data generated by each source (included in S/C inventory units)
    - accounts for sub-products created by on-board processes (and relation to original NDUs)
    - accounts for all level 0 packet streams and NDUs received on earth(including completeness)
    - accounts for NDUs delivered to ground processing facilities
    - accounts for NDUs received from PIs for PDS Archival (relationship to original level 0/1 NDUs)
  - Instrument teams manage the data delivered to them
    - accept responsibility for processing data and delivery to PDS
    - PDS deliveries shall identify relation to original data delivered to Instrument teams
  - Mars Network OPS team provide data handling and delivery for Landed Assets
  - Deep Space Network OPS accounts for telemetry data captured and delivered
    - uses SOEs for projected volumes
    - uses volume froms frames received for comparisons with Packet and NDUs to estimate performance for transformation of frames to Packets and NDUs

Acknowledgement

- The research described during this presentation was carried out by the Jet Propulsion laboratory, under a contract with the National Aeronautics and Space Administration.

CONCLUSION